Agriculture and Environment Research Unit
Science and Technology Research Institute
University of Hertfordshire

The climate change mitigation potential of an EU farm: towards a farm-based integrated assessment

Deliverable 5.1

Final Report

ENV.B.1/ETU/2009/0052

Agriculture and Environment Research Unit
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United Kingdom

4th October 2010

Report Preparation:

Title:	The climate change mitigation potential of an EU farm: towards a farm-based integrated assessment.
Subtitle:	Final Report.
Reference:	ENV.B.1/ETU/2009/0052
Deliverable No.:	5.1
Version:	1
Reporting to:	DG Environment, European Commission.
Reporting period:	November 2009 – October 2010
Project co-ordinator:	University of Hertfordshire, UK
Organisation:	Agriculture and Environment Research Unit Science and Technology Research Institute University of Hertfordshire, UK.
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Report date:	4th October 2010
Release authorisation:	K.A. Lewis

Contents

List of Tables

List of Figures

1.0. Introduction

1.1. Background and overview

Agriculture is multi-functional in terms of the 'goods and services' it provides. As well as producing food, fibre, oils and biomass, it must also function as a habitat for biodiversity, a buffer and filter for pollutants and satisfy the demands of society in terms of the landscape it creates and any environmental pollution or damage it causes. In order to achieve this, the environmental impacts of agriculture need to be fully understood by all stakeholders including farmers, scientists, policy makers and consumers. This is no easy task when consideration is given to the diversity of activities on farms, the materials and energy they utilise and how this is interwoven with a range of habitats, biodiversity and environmental media. The potential environmental effects are numerous and can have a range of direct and indirect impacts, both positive and negative.

This project has developed a 'tentative' model for integrated whole farm assessment (known as IMPACCT - '**I**ntegrated **M**anagement o**P**tions for **A**gricultural **C**limate **C**hange mi**T**igation'), with the objective of encouraging farm practices that will decrease greenhouse gas emissions and increase carbon sequestration, within the context of a sustainable balance between environmental, social and economic objectives as outlined above. The model helps farmers identify practical mitigation options for their specific farm and aids policy makers in identifying practices that could be more widely encouraged across the EU. Thus, this approach follows the philosophy that the underlying science should be the same at the farm level and the policy level.

This project focuses on the contribution of agriculture to climate change, in particular greenhouse gas emissions and carbon sequestration. Specifically this includes the emission (sources) of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and the sequestering of carbon in the soil and plant biomass (sinks). Although the focus is on climate change, it is important not to forget all the other goods and services that agriculture needs to provide. Sustainable agriculture is about finding a balance between environmental, economic and social objectives. Achieving one objective (i.e. climate change mitigation) should not be pursued at the expense or exclusion of other objectives. Agriculture needs to be economically viable, produce enough food, fibre and oils to equitably meet the needs of an increasing global population, and ensure that any other detrimental environmental impacts are minimised to acceptable levels.

The project consisted of 6 tasks:

1. **Identification of the main types of EU farming systems**. This included establishing a farming system typology to use, breaking down farming systems in component parts (activities) for which emissions data would be sought, and reviewing literature to create a knowledge base on emissions from agriculture.
2. **On-farm mitigation actions**. This included a review of literature and data sources to identify practices that have the potential to reduce emissions or increase carbon sequestration; a national consultation exercise to establish approaches to mitigation in different member states; and Phase 1 case studies of farms across 7 EU member states that have already implemented mitigation options.
3. **Impacts on other environmental objectives**. This included a review of literature and data on a range of different impact categories including air, soil and water quality, biodiversity, ozone depletion, resource

use, waste and recycling, landscape and heritage and public safety and nuisance, in order to determine any synergies or trade-offs between climate change mitigation practices and the objectives for these impact categories.

4. **Integrated Whole Farm Assessment**. This task developed the 'tentative' model known as IMPACCT and included establishing the requirements of the tool at the farm and policy levels, design, creation and population of the core database, development of mechanisms to deal with gaps and uncertainty in data, development of calculation routines and development of user interfaces for the software.
5. **Policy opportunities analysis**. This task examined the potential of the IMPACCT model for knowledge transfer and also used the policy assessment tool within the software to explore the potential for widespread adoption and identify any barriers to adoption. This task was also part of the testing process for the policy assessment tool.
6. **Proofing the model**. This task involved testing the IMPACCT model at the farm level and then refining and polishing it. It included in-house testing with hypothetical case study farms and Phase 2ii case studies on real farms across 7 EU member states. This provided feedback on the general usability and usefulness of the tool at the farm level.

This document is the final report (Deliverable 4) of the project and provides a description of work undertaken throughout the entire period of the project (November 2009-September 2010), including the work undertaken between June and August that has not been previously reported on, which includes Task 5: Policy opportunities analysis and Task 6: Proofing the model using the Phase 2ii farm case studies.

This report consists of the following sections:

- **Project overview**: Details of the background, aims and objectives of the project, the structure of the approach, the tasks and the consortium of partners involved in the project.
- **Technical description of the work**: Detailed reports on each of the 6 tasks within the project. This forms the bulk of the report and includes details of all the key outputs.
- **Administrative issues**: Details of what has been undertaken in relation to the administration of the project and performance in relation to schedule of work.
- **Discussion**: A brief discussion on the outputs and findings of the work undertaken.

An addition to these sections there are number of appendices, including Appendix A which includes detailed information on each of the 21 case studies undertaken as part of testing the IMPACCT software. These case studies have not been made available in any previous project reports and they are not available on the project website (as they contain sensitive information for specific farms), hence they have been made fully available within Appendix A of this report.

1.2. Methodological issues

There are number of key methodological issues the lay behind the concept and approach taken to this project and the development of the 'tentative' model. These include:

- The farm and policy level approach
- The approach to boundary setting and structuring emissions (and other) data
- Limited and time and resources for the project

Farm and policy level

The aim of the project is to develop a 'tentative' model that can be used both at the policy and farm levels, to aid both policy makers to make strategic decisions to reduce greenhouse gas emissions, and to help farmers adopt practices will also achieve the same objective, by presenting them with mitigation options that are relevant and effective for their specific farm. It is the combination of both these stakeholders, working in harmony, which is likely to result in the greatest potential to make significant reductions in emissions across the agricultural sector. The philosophy of this project is that the underlying science should be the same at the farm level and the policy level, as all too often in the past decisions made at the policy level are based on different data and information than the decisions made at the farm level, and in some instances contradictory information can exist. Therefore, at the heart of our approach is a common core database, which is used by both the policy and farm assessment tools within the model, thus ensuring that both levels are working with the same data, information and scientific evidence base.

Boundary setting and data structuring

A crucial element of any environmental assessment is the data that is used to underpin it, and how that data is managed and structured, especially within the context of serving both the policy and farm levels. Our approach has followed many common methods and standards, similar to life cycle assessment, and utilising established techniques where available. A key part of this approach was to establish a clear farm typology and a breakdown of farm systems and enterprises into components against which data can be stored and managed and assessments made. This included identifying direct and indirect emission sources, for example, where inorganic fertiliser are used on a farm, there are components for the emissions from the actual application (direct), emissions from the manufacture and transport of the fertiliser (indirect) and then emissions from the fate of the fertiliser after application (direct). This 'modular' structure allows users of both the farm and policy tool, to build up farm profiles by picking the components that apply to a farm, or explore specific components only in a 'what if' fashion. In so doing this provides transparent boundaries to the assessment. It also provides a very clear structure for the core database, enabling easy updating with more up to date data in the future.

Limited and time and resources

All projects have limited time and resources available with which to achieve their objectives. The important aspect is to identify what can be achieved within those limitations and what is the most cost-effective approach in order to ensure maximum value for money. In order to achieve the objectives of this project within the time available (11 months) our approach aimed to utilise and reuse as much data as possible that had been generated from previous projects undertaken by the project partners and others. A substantial amount of data had already been collated in previous projects and this was added to by a comprehensive review of data and literature and by the case studies undertaken in the 7 Member States. Additionally, the project utilised rapid prototyping techniques to develop the IMPACCT software, which saved a lot of time and allowed the second phase of case studies to proceed on schedule. Finally, full use was made of communications technology to reduce time and travel costs working with both the Commission and the project partners.

2.0. Project Overview

2.1. General background

This project focused on the contribution agriculture makes to climate change, in particular greenhouse gas emissions (sources) including carbon dioxide, methane and nitrous oxide and the sequestering of carbon in the soil and plant biomass (sinks). The balance of sources and sinks, will determine the emissions profile of a farm and thus the overall contribution towards climate change mitigation. The purpose of this study was to help prepare concepts and tools to facilitate farmers and growers take action to reduce their greenhouse gas emissions and improve carbon sequestration in order to mitigate climate change impacts. The work also provides support for policy makers in the development and improvement of climate change mitigation policies.

This project aimed to develop a 'tentative' model for integrated whole farm assessment, with the objective of encouraging farm practices that will decrease greenhouse gas emissions and increase carbon sequestration, within the context of a sustainable balance between environmental, social and economic objectives. It was anticipated that this model would help a farmer identify practical mitigation options for their specific farm and will also aid policy makers in identifying practices that could be more widely encouraged across the EU. The model development process was supported by a comprehensive literature and data review and a number of farm case studies / consultation exercises that was undertaken in seven EU Member States. This process helped define the requirements of the model, based on the needs of end users, and provide concrete examples of mitigation actions.

The project contract was agreed and signed in November 2009 and ran 11 months ending in October 2010.

2.2. The project consortium

Figure 2.2.1 shows the coverage of EU member States that is provided collectively by the sub-contractors and Table 2.2.1 provides details of the eight organisations in the project consortium.

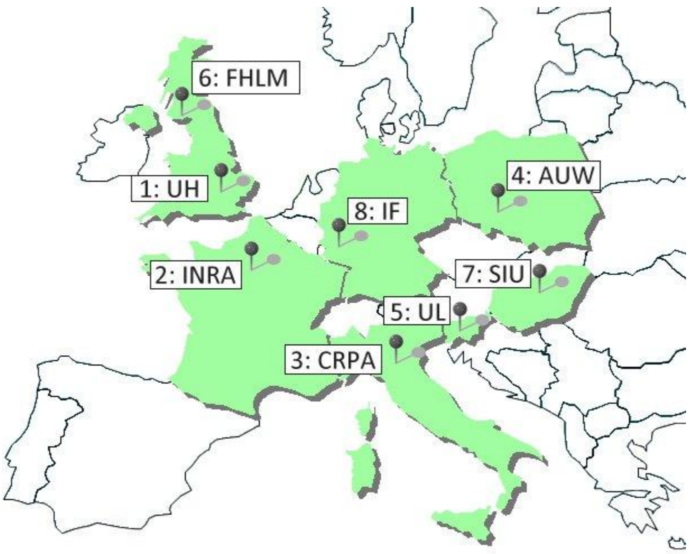


Figure 2.2.1: EU Member State case study coverage

Table 2.2.1: The project consortium

	Sub-contractor Abbreviation [Contact name]	Legal Name & EU Member State	Project role
1	UH [Dr Kathy Lewis]	University of Hertfordshire, ENGLAND, UK	Lead contractor; Project coordinator; Technical lead; UK consultation exercise.
2	INRA [Dr Hayo van der Werf	I'institut National de la recherché agronomique, FRANCE	Case studies on 6 farms; French consultation exercise; Reporting activities relating to Task 2 and 6.
3	CRPA [Prof.Giuseppe Bonazzi]	Centro Ricerche Produzioni Animali , ITALY	Case studies on 4 farms; Italian consultation exercise; Reporting activities relating to Task 2 and 6.
4	AUW [Dr Wieslaw Fialkiewicz]	Agricultural University of Wroclaw, POLAND	Case studies on 8 farms; Polish consultation exercise; Reporting activities relating to Task 2 and 6.
5	UL [Dr Rok Mihelic]	University of Ljubljana, SLOVENIA	Case studies on 6 farms; Slovenian consultation exercise; Reporting activities relating to Task 2 and 6.
6	FHLM [Kirsty Hutchison]	FH Land Management, SCOTLAND, UK	Case studies on 5 farms; Reporting activities relating to Task 2 and 6.
7	SIU [Márton Jolánkai]	SIU Crop Production Institute, Szent István University, HUNGARY	Case studies on 10 farms; Hungarian consultation exercise; Reporting activities relating to Task 2 and 6.
8	IF [Dr Christian Friedrich]	Ingenieurbüro Feldwisch, GERMANY	Case studies on 4 farms; German consultation exercise; Reporting activities relating to Task 2 and 6.

2.3. Study objectives

The principal policy objective of this project was to help reduce GHG emissions and increase carbon sequestration in the agricultural sector for the purpose of climate change mitigation. This project aimed to contribute towards that policy objective by providing support to:

- Farmers to enable them to take action to mitigate climate change by appropriately modifying their farming practices.
- Policy makers to enable them to develop policies in order to support climate change mitigation.

A number of specific objectives were identified including:

1. To better understand the GHG profile of common farm practices in the EU, and how these practices fit into the major farming systems.
2. To understand how changes to these practices can improve the GHG profile.
3. To propose a 'tentative' model for a whole-farm assessment of GHG profile, designed to be adjustable for changes in farming practice; and to provide the basic concepts and tools necessary for making this assessment. This should include a preliminary analysis of the administrative actions needed to make this function.
4. To understand the potential synergies between the different practices discussed, as well as understanding the potential environmental disadvantages of the practices (e.g. if they could cause damage to biodiversity, water, soil, or landscape etc).

The heart of the project was the development of the model (Objective 3), with each of the other objectives providing building blocks to support this. The approach that was adopted followed a philosophy that the same science should be used by all stakeholders from the farm to the policy level. This helps ensure that everyone is working with a common set of principles, concepts and data, thus helping to avoid differences in environmental assessments and aiding consensus.

2.4. Structure and Tasks

The project was designed around four key themes as shown in Figure 2.4.1 below. These are:

A. **Project tasks:** the key steps to be undertaken during the project.

B. **Model structures:** the framework around which the model will be constructed.

C. **Data:** the data and information that will feed the model.

D. **Case studies and consultation:** to provide data and concrete examples from real farms.

Themes 1 to 3 were carried out by the project contractor (the University of Hertfordshire). Theme 4, the European case studies, was coordinated by the University but carried out locally by a number of sub-contractors.

A. Project Tasks

The work was organised into a number of project Tasks which divided the work in to five discrete phases plus an additional one dedicated to project management and administration (Task 0). These Tasks, which were the key steps to be undertaken during the project, are summarised in Table 2.4.1.

Table 2.4.1: List of project tasks

Number	Brief description
Task 0	T0: Project management, co-ordination and reporting
Task 1	T1: Identification of the main types of EU farming systems
Task 2	T2: On-farm mitigation actions
Task 3	T3: Impacts on other environmental objectives
Task 4	T4: Integrated whole farm assessment
Task 5	T5: Policy opportunities
Task 6	T6: Proofing the model

B. Model structures

A key part to this project was the structuring of farming systems, farm types and farm system components. The final classification of farm types and their breakdown into components adopted for the study formed the fundamental structure of the knowledge base and the core database that is used within the 'tentative' model.

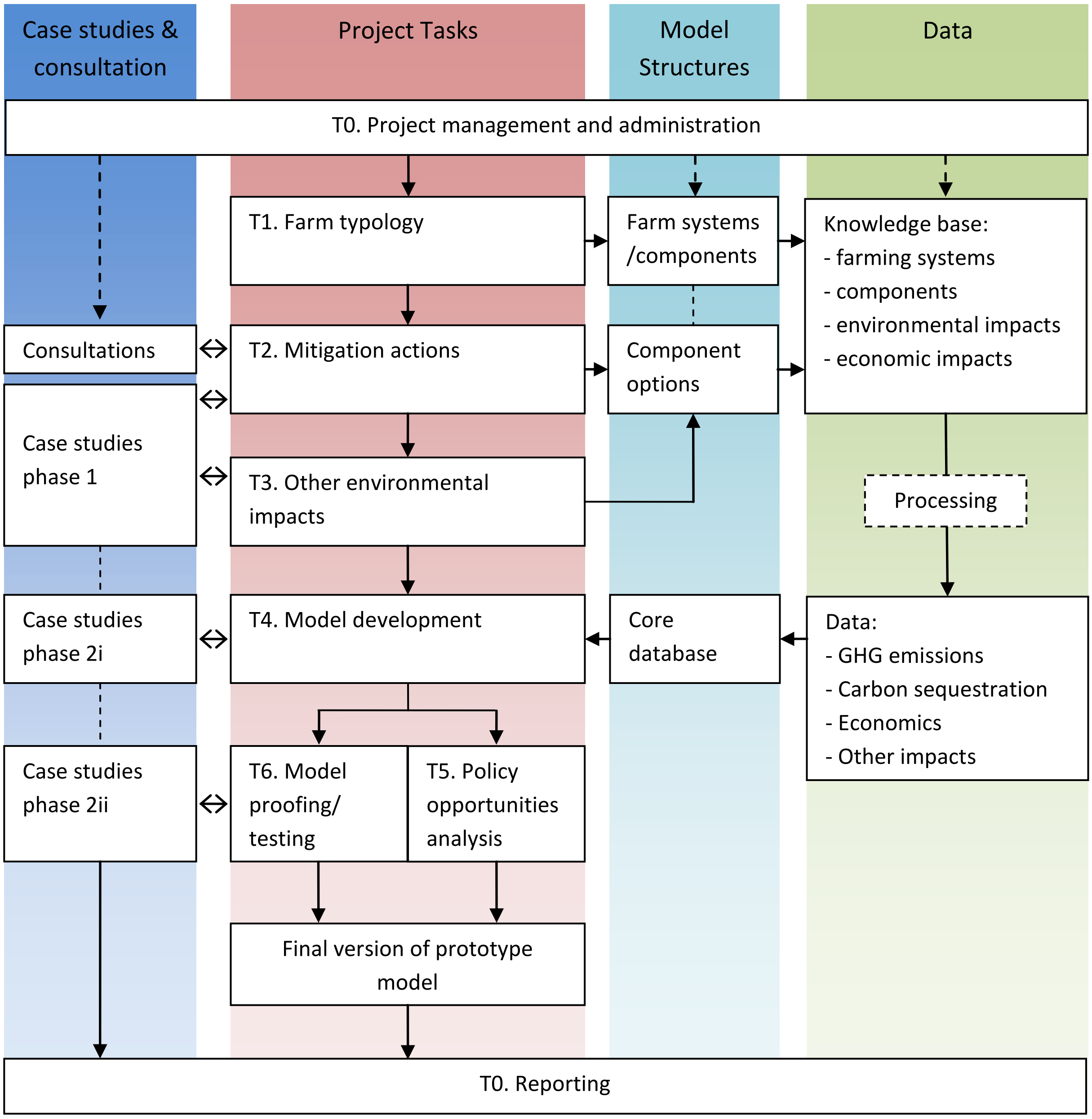


Figure 2.4.1: Project flowchart

It is important to acknowledge that agriculture and the farming landscape we endeavour to understand is an open continuum with geological, biological, chemical and physical processes at work, with flows of materials and energy within a global system. However, in order to be able to understand, assess and evaluate farms and farming systems, we inevitably have to break them down into their component parts. It is a process of abstraction in order to 'paint' the best scientific picture in order to make sound decisions, be that at the policy or farm level. Identifying different farm system components also helps us to identify key intervention points, i.e. where in the system are the greatest GHG emissions. These intervention points can then become the focus for developing mitigation options.

Figure 2.4.2 illustrates the flows of material and energy within an agricultural system, whilst also showing how we can start to breakdown the system into a set of farm system components through which the materials and energy flow.

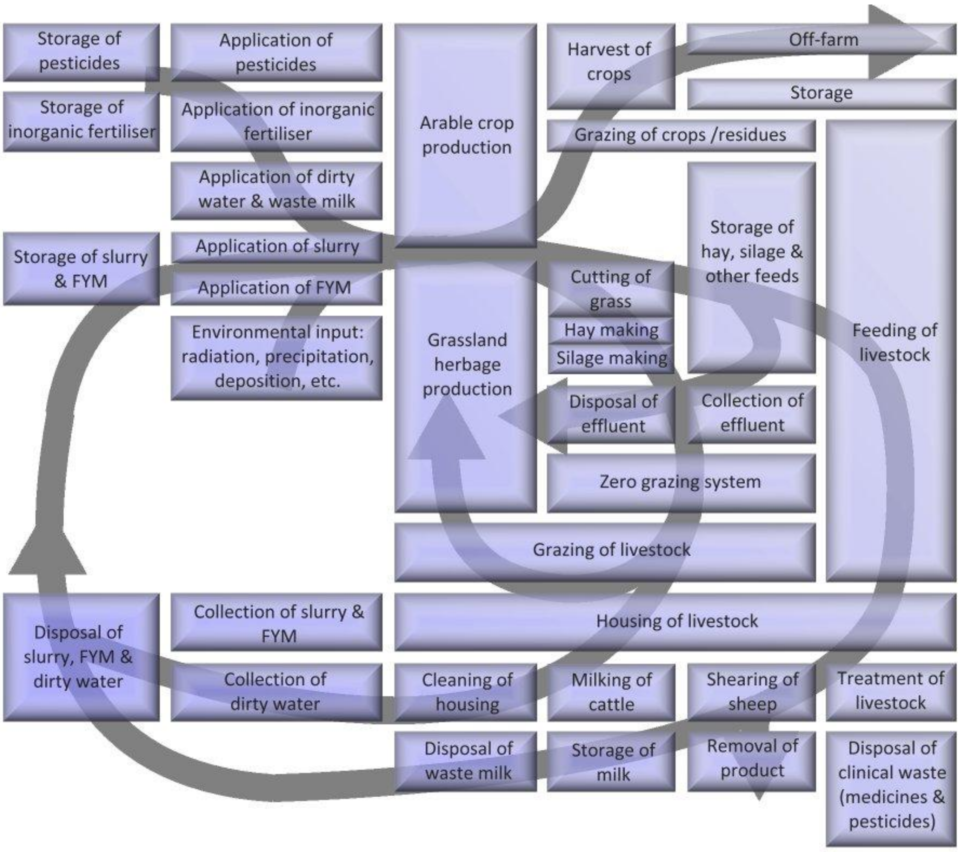


Figure 2.4.2: Flows of materials and energy in a farm system

Task 1 dealt with the process of classifying farming systems and breaking them down into their component parts. Farm system components covered a variety of items and actual physical units on the farm such as housing or machinery, as well as processes such as field operations and soil nutrient management, i.e. 'components' is a generic term to cover the range of different parts of the farm system.

C. Data generation and identification

The data used within any environmental assessment is a key factor and can have a big influence on the outcome of the assessment. The computer science term 'Garbage In Garbage Out' (GIGO) applies to this project in that the model will use and process any data it is supplied with, not only in terms of the data that the user inputs, but also with respect to all the data that underlies the model. Thus it was considered essential that the core database is populated with the most recent and reliable data that was available in order to ensure that the results generated are accurate and sensible.

Previous work undertaken by the main contractor (Lewis *et al*., 1999; Lewis *et al*., 2002; Tzilivakis *et al*., 2005a & b; Warner, 2005, 2007 & 2008) on GHG emissions and carbon sequestration resulted in a substantial database of agricultural related emissions data that were used as a starting point. Other data was identified during a comprehensive literature and data review undertaken in Tasks 1, 2 and 3 and numerous other data sources, such as the IPCC's Emissions Factor Database (EFDB). The data included on farm emissions (to the farm gate) from fuel consumption (spraying or spreading, irrigation, tillage operations and drilling, heating and lighting of livestock housing and glasshouses, crop drying), emissions from soil (CO_2, N_2O and CH_4), livestock (enteric fermentation, manures and their storage), and considered potential impacts on C in soil and plant biomass. It also included upstream (indirect pre-farm) emissions from product manufacture (pesticides, fertilisers, polyethylene for polytunnels and mulch, their packaging, storage and transport to the farm) and machinery manufacture (based on depreciation per operation).

D. Case Studies and Consultations

Case studies were considered a key theme within this project with their outputs being used to underpin the findings of the other tasks and provide concrete examples with respect to GHG emissions and carbon sequestration. There were two phases of case studies, with the second phase split into two parts:

- **Phase 1**. Undertaken in Task 2, these case studies focused on farms where some GHG mitigation options had already been implemented and sought to obtain farm data on practices that have been implemented to reduce GHG emissions or increase carbon sequestration, and their associated economic and other environmental impacts.
- **Phase 2**. These case studies were undertaken in Tasks 4 and 6 on farms where very little GHG mitigation actions had been undertaken:
    i. Case studies in Task 4 introduced the 'blueprint' of the 'tentative' model to farmers and other stakeholders in order to obtain feedback their feedback on what was being proposed. This feedback would then be used to refine the design of the model prior to construction to ensure it met end user requirements.
    ii. Case studies in Task 6 applied the beta-version of the model to actual farm situations, thus testing it with actual farm data. The findings of these case studies were then used to refine the model.

The case studies were undertaken by a network of sub-contractors on real farms in seven different EU Member States (see Table 2.2.1 and Figure 2.2.1) and these provided a reasonable coverage of the EU and a good cross section of farm types include a range of livestock and cropping enterprises. However, it was recognised that the coverage of EU Member States could be improved and efforts were made to engage other Member States (for example Spain and the Nordic countries) by inviting individuals to pilot the draft software. In addition to these real case studies several hypothetical case studies were developed which demonstrate how the model could be used and the potential benefits on offer to both farmers and policy makers.

As well as case studies a consultation exercise was undertaken to obtain views, opinions and knowledge on GHG emissions and carbon sequestration in the farming sector in the seven EU Member States represented by the project partners. The consultation exercises took the form of structured interviews based around a questionnaire developed specifically for the purpose.

3.0. Technical Description of the Work

This section describes in detail the work that was undertaken in order to deliver the project objectives. Six individual Tasks were undertaken. Tasks 1, 2 and 3 together comprised a comprehensive literature review, consultation process and case studies that underpinned the project. Tasks 4 and 6 addressed the development and testing of the model. Task 5 explored the policy opportunities and implications of adopting mitigation options on farms across the EU. In addition to these Tasks there is a non-technical one, Task 0 that addressed project organisation, management, coordination and reporting.

3.1. Task 0: Project Management

Activity Start Date	M1	Activity Finish Date	M11
Milestones and Deliverables	Project meeting minutes all submitted and approved on schedule Project reports all submitted and approved on schedule		
Key project partners involved	University of Hertfordshire		

The project coordinator (The University of Hertfordshire (UH)) has been responsible for the delivery, quality and management of the project. Project management activities have been undertaken as Task 0 (see Table 2.2.1)**.** These are broken down into two main Activities.

3.1.1 Activity 0.1: Overall administrative co-ordination

The main activities undertaken have included:

- Contractual and financial management between project the University of Hertfordshire and the European Commission and between the University and it's sub-contractors;
- Establishing a coordination strategy between project partners;
- Coordination of project activities including progress monitoring, ensuring milestones are met and that the scientific quality of the project is high.
- Production of the project Inception report and attendance at a Kick-off meeting;
- Production of other project reports and project meetings.

3.1.2 Activity 0.2: Dissemination

The main activities have included establishing a public face for the project, engaging with stakeholders, reporting and dissemination. The main activities undertaken have included:

- **Establishing a public face for the project**

Whilst the project has an official title, in order for it to be more easily disseminated, referred to and recognised the project and its deliverables / outputs ideally needed a name and branding. The name adopted is **IMPACCT** and is an acronym for 'Integrated Management oPtions for Agricultural Climate Change miTigation'. Figure 3.1.1 shows the project logo and branding style adopted.

Project logo **Project branding style**

Figure 3.1.1: Project logo and branding style

- **Development of a project website**

A project website (http://www.herts.ac.uk/aeru/impacct/) has been developed using the IMPACCT name and branding. This website is shown in Figure 3.1.2 and includes:

❖ An overview page which provides a brief description of the project based on the original public tender document;
❖ A description of the project partnership;
❖ A project news page;
❖ A page inviting stakeholders to take part in the consultation exercises and testing/piloting the model;
❖ An area where the project information can be downloaded.
❖ An area where the beta-version of the 'tentative' model can be downloaded for testing and piloting;
❖ Contact details for the project coordinator.

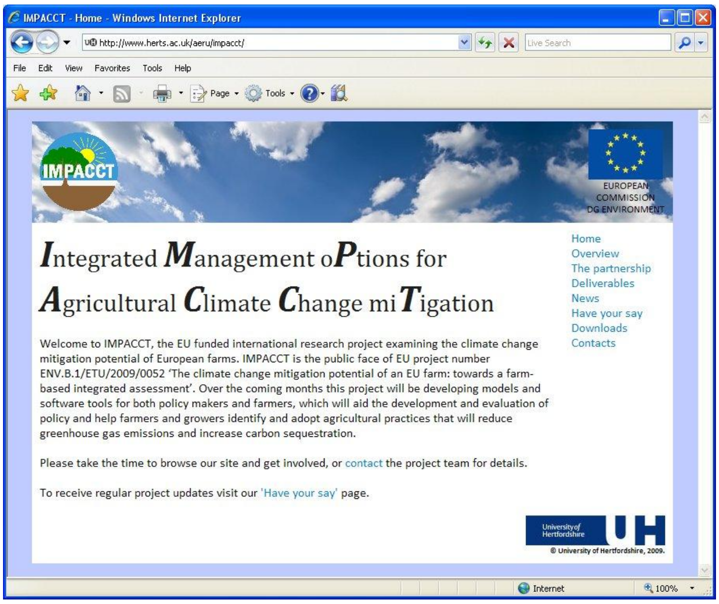


Figure 3.1.2: Welcome screen of the project website

- **Dissemination activities**

A number of dissemination activities have been undertaken. These include

❖ A project leaflet has been created, agreed by the consortium and is available as a download from the project website;

- A poster was presented at the 'The Dundee Conference - Environmental Management and Crop Protection' to be held in Dundee, Scotland on 23rd-24th Feb 2010. The poster can be downloaded from the project website;
- Two project newsletters have been produced and circulated. These are on the project website;
- The European case studies (Phase 1 and Phase 2) undertaken. Phase 1 case study sheets are available for download from the project website. Phase 2 case studies are available in Appendix A.

3.2. Task 1: Identification of the main types of EU farming systems

Activity Start Date	M1	Activity Finish Date	M2
Milestones and Deliverables	Breakdown of farming types by components		
Key project partners involved	University of Hertfordshire		

The 'tentative' model required a suitable structure on which to undertake calculations of greenhouse gas emissions, carbon sequestration and other impacts. It also needed to operate at the both the farm and policy levels and provide suitable boundaries to the system that is assessed (e.g. differentiating direct and indirect emissions). Our approach to providing this structure was to identify a suitable farm typology that is familiar at the policy level and then breakdown the farming enterprises within that typology into component parts at the farm level. In so doing this provided the key mechanism for structuring data in the core database of the 'tentative' model, a hierarchical means of reporting emissions, sequestration and other impacts at both the farm and policy levels and a way of allocating emissions and sequestration to specific products from different enterprises. Our approach to identifying the typology and farm system components is described below.

3.2.1. Activity 1.1. Identifying the farm typology

The project methodology (Task 1) involved establishing a farm typology and breaking different farm types into their component parts. In order to avoid 'reinventing the wheel' the first part of the work involved a review of the farm typologies; both those being used in practice and those that have been proposed within the scientific literature. It was considered that if it was possible to adopt a typology already in use this would offer benefits as it would ensure a familiar framework underpinned the research and would save time and resources. The key requirements of the process was to establish a system by which emissions and sequestration data could be 'mapped' from the production activity (component) back to a 'farm type' and vice versa (Task 2). For example emissions data for a particular type of livestock housing (a component) can be linked to a particular type of livestock farm whereas they may be considered irrelevant for arable farms or horticultural holdings.

There are many definitions of what constitutes a farming typological system (Benedict *et al*., 1944; Hurley, 1965; Landais, 1998; Pretzer and Finley, 1974). However, they can be defined as a "population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate" (FAO, 2004). The rationale for such classifications assumes that if farms are placed into more homogeneous groups it would aid the understanding of the diversity in the farming sector.

There are many different farm typologies in practical use globally and the process of classification has been the subject of research for many decades (e.g. Hurley, 1965; Pretzer and Finley, 1974). The review process identified a wide range of different systems. There are those that are based on, for example, the farm economic status such as sales volume, production capacity or net operating income. For example, a theoretically grounded farm typology for Sweden based on patterns of labour use and sources of income was suggested by Djurfeldt and Waldenstrom (1996) and there are many others (e.g. Alvarez-Lopez *et. al.,* 2008; Davis *et al*., 1997; Divila and Doilicha, 2005; Henke, 2007; Hoppe *et al*., 2000; Riveiro *et al*., 2008;).

Some take this approach a step further and classify farms on the basis of the farm strategy or policy (Briggeman *et al*., 2007; de Bont, 2005; Edmund *et al*., 2004; Silvis, 2005). The United States Department of Agriculture (USDA) have grouped farms according to their contribution to US agricultural production, their products, scheme/programme participation, and dependence on farm income (USDA, 2000; 2001). Agriculture and Agri-Food Canada developed a farm typology very similar to that used by the USDA that also goes beyond the basic typologies and is based on farm size, contribution to total agricultural production or national net farm operating income. Factors such as age, income, business intentions and revenue class are used to categorize farm operators and farm families into distinct groups (AAFC, 2002).

There are also some that are of a more specialist nature such as classifications based on survival strategies or diversification options in a financially stressed agricultural industry (e.g. Daskalopoulou and Petrou, 2002; Mack *et al*., 2006). Smit and Skinner (2002) described a typology that systematically classified farming options to climate change based primarily on the Canadian situation. In this instance the aim was to be able to differentiate different farming systems in the context of GHG emissions and carbon sequestration. Another example is that proposed by Garcia *et al*. (2009) that classified farms based on their size and productive orientation using indicators of sustainability.

Considering the tasks that must be accomplished with the chosen typology those identified above do not permit the individual components of a particular farming system to be easily identified. In addition some classify farms according to variables that are not directly relevant to the study. Consequently they are not suitable for use within this project and so have been dismissed.

There are typologies that combine the main types of farming activities and the economic status of the business and these are the most widely used. Within the European Union Member States use a farm typology to aid in the analysis of their national farming industry and to collate data for the EC Farm Structure Survey managed by the Statistical Office of the European Communities (Eurostat). The typology rationale assumes that by classifying farms by size and type policy can be better targeted at particular farms and the impact of policy can be analysed in more detail. It also helps establish more clearly the relationships that farm size and type have with profitability, efficiency and other significant variables. This EU typology is described in Commission Decision 85/377/EEC as amended by Commission Decision 94/376/EC. The system is based on the Standard Gross Margins per hectare for crops and per capita for livestock (Defra, 2005; Eurostat, 2006; Yoemans, 1984) and determines farm type according to the relative contribution of different activities to the Standard Gross Margin (SGM).

It appears that this typology suits the current project as it classifies farm activities at a sufficient level of detail and in a manner that would enable production activities and farm types to be mapped. There are also benefits as national agricultural census data might then be used relatively easily to scale up climate change mitigation benefits as calculated by the 'tentative' model to a national level – a task that may be of value to policy makers. However, the approach is not without its problems.

A typology that is broad enough to cover all the diverse farming types in the EC will undoubtedly mean that not all farm types described are applicable to all Member States. In the UK, for example, the standard EC system has been slightly modified to better represent UK mainstream agriculture and does not include certain specialist types of which there either few examples in the UK or types which whilst numerous, are not economically significant (Andersen *et al*., 2007; Defra, 2007). This type of issue may cause minor problems associated with scaling and extrapolation if there is not an exact match between that used in the 'tentative' model and national data. However, this is an issue beyond the control of the project researchers.

Another potential problem is associated with farm size and their inclusion in the agricultural survey. In some EU Member States, typically those around the Mediterranean such as Greece, Portugal and Italy, and some others such as Hungary, much of the agricultural industry is comprised of relatively small units that are often less than 20 ha in size and in many cases less than 5 ha. For comparison Sweden, Denmark and Norway are typically around 40 ha and the UK is nearer 70 ha (Godinho and Coelho, 2005; Laczka and Szabó, 2000). The typology defines farm size on the basis of European Size Units (ESU). The ESU is a measure of economic size rather than physical size as it takes production intensity into account. Member States can define national ESU threshold values for holdings that are included in the survey provided such definition guarantees the requisite coverage that any individual farm unit is at least one hectare in size and the total contribution of farm units excluded from the census to the SGM must not exceed one per cent. In the UK, for example, the threshold is set at 8 ESUs whereas it has been proposed that the threshold for Hungary needs to be just 1 ESU (Laczka and Szabó, 2000). Adding to the problem is the fact that these types of small holdings often produce purely for their own family consumption and such farms are excluded from EU statistics by definition. However, they do contribute significantly towards national economies and excluding them would mean a substantial understatement of the agricultural output of such countries (Laczka and Szabó, 2000) and, if the data is used to scale up the potential climate change mitigation benefits, these would also be substantially underestimated. However, as long as such issues are made transparent within the 'tentative' model for policy makers such problems are not considered significant enough to use an alternative typology which is just as likely to have problems of its own.

Consequently, the EU typology has been selected to be used in the 'tentative' model. Table 3.2.1 shows the breakdown of farm types into four levels of farming:

– 9 General types of farming,
  – 17 Principal types of farming,
    – 50 Particular types of farming,
      – 32 Sub-groups of certain particular types of farming.

Table 3.2.1: EU farm Typology

General Type (GT)		Principal Type (PrT)		Particular Type (PaT)		Sub-groups (SG)	
1	**Field crops**	**13**	**Specialist cereals, oilseeds & protein crops**	131	Specialist cereals, oilseeds & protein crops, not rice		
				132	Specialist rice		
				133	Cereals, oilseeds, protein crops and rice combined		
		14	**General field cropping**	141	Specialist root crops		
				142	Cereals & root crops combined		
				143	Specialist field vegetables		
				144	Various field crops	1441	Tobacco
						1442	Cotton
						1443	Various field crops combined
2	**Horticulture**	**20**	**Specialist horticulture**	201	Specialist market garden vegetables	2011	Specialist market garden vegetables - outdoor
						2012	Specialist market garden vegetables - under glass
						2013	Specialist market garden vegetables - outdoor & under glass combined
				202	Specialist flowers & ornamentals	2021	Specialist flowers & ornamentals - outdoor
						2022	Specialist flowers & ornamentals under glass
						2023	Specialist flowers & ornamentals - outdoor & under glass combined
				203	General market garden cropping	2031	General market garden cropping - outdoor
						2032	General market garden cropping – under glass
						2033	Specialist mushrooms
						2034	Various market garden crops combined
3	**Permanent crops**	**31**	**Specialist vineyards**	**311**	Quality wine		
				312	Wine other than quality		
				313	Quality & other wine combined		
				314	Vineyards	3141	Table grapes
						3142	Raisins
						3143	Mixed vineyards
		32	**Fruit & citrus**	**321**	Fruit, no citrus	3211	Fresh fruit, no citrus
						3212	Nuts
						3213	Fruit & nuts combined, no citrus
				322	Citrus		
				323	Fruit, citrus & nuts combined		
		33	**Olives**	**330**	Olives		
		34	**Various permanent crops combined**	**340**	Various permanent crops combined		
4	**Grazing livestock**	**41**	**Specialist dairying**	**411**	Dairy (Milk)		
				412	Dairy (Milk) & cattle rearing		

General Type (GT)		Principal Type (PrT)		Particular Type (PaT)		Sub-groups (SG)	
		42	**Specialist cattle rearing & fattening**	**421**	Cattle rearing		
				422	Cattle fattening		
		43	**Cattle-dairying with rearing & fattening**	**431**	Dairy with rearing & fattening		
				432	Rearing & fattening with dairy		
		44	**Sheep, goats & other grazing livestock**	**441**	Sheep		
				442	Sheep & cattle combined		
				443	Goats		
				444	Various grazing livestock		
5	**Granivores**	**50**	**Specialist granivores**	**501**	Specialist pigs	5011	Specialist pig rearing
						5012	Specialist pig fattening
						5013	Pig rearing & fattening
				502	Specialist poultry	5021	Specialist layers
						5022	Specialist poultry meat
						5023	Layers & poultry meat combined
				503	Various granivores combined	5031	Pigs & poultry combined
						5032	Pigs, poultry & other granivores
6	**Mixed**	**60**	**Mixed cropping**	**601**	Market gardening & permanent crops		
				602	Field crops and market gardening		
				603	Field crops & vineyards		
				604	Field crops & permanent crops		
				605	Mixed cropping – mainly field crops		
				606	Other mixed cropping	6061	Mixed cropping – mainly market gardening
						6062	Mixed cropping mainly permanent crops
7	**Mixed livestock**	**71**	**Mixed livestock – mainly grazing**	**711**	Mixed livestock – mainly dairy		
				712	Mixed livestock – mainly non-dairy grazing		
		72	**Mixed livestock – mainly granivores**	**721**	Mixed livestock – granivores & dairy		
				722	Mixed livestock – granivores & non-dairy		
				723	Mixed livestock – granivores with various livestock		
8	**Mixed crops - livestock**	**81**	**Field cropping-grazing livestock combined**	**811**	Field crops & dairy		
				812	Dairy & field crops		
				813	Field crops & non-dairy grazing		
				814	Non-dairy grazing & field crops		
		82	**Various crops & livestock combined**	**821**	Field crops & granivores		
				822	Permanent crops & grazing livestock		
				823	Various mixed crops & livestock	8231	Apiculture
						8232	Various mixed holdings
9	**Non-classifiable**						

3.2.2. Activity 1.2. Farm system components and data identification

The objective of this Activity was to examine each of the farming systems within the selected Typology and break these down into their component parts with respect to physical units, activities, practices and processes. Figure 2.4.2 illustrates the concept for a livestock farm.

The first step involved taking the information provided in Table 3.2.1 and extracting a list of unique farming types. These are given in Table 3.2.2. Note for the purposes of this particular research project the farming categories 31 (Other granivores), 32 (Apiculture) and 33 (Others) have been omitted.

Table 3.2.2: Unique farm enterprises

Enterprise UH ID (EID)	Description		
1	**Cereals**	**Field crops [1 to 8]**	
2	**Oilseeds**		
3	**Protein crops**		
4	**Rice**		
5	**Root crops**		
6	**Field vegetables**		
7	**Tobacco**		
8	**Cotton**		
9	**Market garden vegetables - outdoor**	**Horticulture (Market gardening) [9 to 13]**	
10	**Market garden vegetables - under glass**		
11	**Flowers & ornamentals - outdoor**		
12	**Flowers & ornamentals under glass**		
13	**Mushrooms**		
14	**Quality wine**	**Vineyards [14 – 17]**	**Permanent crops [14 – 21]**
15	**Other wine**		
16	**Table grapes**		
17	**Raisins**		
18	**Fresh fruit, not citrus**	**Fruit [18 – 21]**	
19	**Nuts**		
20	**Citrus**		
21	**Olives**		
22	**Dairy (milk)**	**Graving livestock [22 – 26]**	
23	**Cattle rearing**		
24	**Cattle fattening**		
25	**Sheep**		
26	**Goats**		
27	**Pig rearing**		
28	**Pig fattening**		

Enterprise UH ID (EID)	Description	
29	**Poultry layers**	**Granivores [27 – 31]**
30	**Poultry meat**	
31	Other granivores	
32	Apiculture	
33	Other	

The next step in Activity 1.2 was to break each unique enterprise (Table 3.2.2) down into the component parts. The process of breaking down each of the enterprises into components is linked to the design and structure of the core database (see Section 3.5.2, Activity 4.2). In theory there will be multiple components to each enterprise, sub-components of each component and sub-components of each sub-component, etc. The scope for having multiple levels of components is large and this is not very compatible for developing a standard format in which to store the data in the core database. At this stage of the project each enterprise has been given a general classification category and two levels of components (primary and secondary). Amendments and further component levels may need to be made as the project progresses.

These general categories are useful from an organisational perspective. An additional structural layer also exists in the form of 'Modifiers'. These provided a framework to allocate different data (i.e. emissions, sequestration, economics, etc.) to single sub-components, based on variables within those components. Table 3.2.3a provides an example for the Enterprise of Cereals and includes the component categorisation and relevant modifiers. Table 3.2.3b shows a similar table for a cattle rearing enterprise.

Table 3.2.3a: Cereals Enterprise Components

Category	Primary component	Secondary sub-component	Modifiers
Soil Management	Seedbed preparation	Ploughing	Soil type & Ploughing depth
		Harrow	Equipment type
		Subsoil	Soil type
Crop nutrition (arable)	Inorganic fertilisers	Production	Fertiliser type
		Application	
	Organic fertilisers	Loading	
		Transport	
		Application	Manure type and Soil type
Crop protection	Pesticides	Production	Pesticide type
		Application	Technique/formulation
Water use	Irrigation	Application	
Harvesting	Harvesting	Harvest in field	
		Transport	
Product storage	Product drying	Drying wheat grain	
		Drying barley grain	
	Product cooling	Cooling cereal grain	

Table 3.2.3b: Cattle Rearing Enterprise Components

Category	Primary	Secondary	Modifiers
Livestock	Beef cattle	Beef cattle enteric fermentation	Breed and diet
		Beef cattle excreta (deposition on pasture)	Dairy cow size, breed and diet
		Beef cattle FYM Housing	Breed, diet and equipment
		Beef cattle FYM Storage	Breed, diet and equipment
		Beef cattle Slurry Housing	Breed, diet and equipment
		Beef cattle Slurry Storage	Breed, diet and equipment
Crop nutrition (grassland)	Inorganic fertilisers	Production	Fertiliser type
		Application	
	Organic fertilisers	Loading	
		Transport	
		Application	Manure type and Soil type
Waste management	Slurry and manure	Slurry storage	Type of slurry and type of store
		Manure storage	Type of manure and type of store

Tables 3.2.3a and 3.2.3b show the components that are enterprise specific, they do not include components that may be generic to all farms, for example, different fuel and energy sources, the management of environmental areas on the farm (e.g. hedgerows), or changes in land use (e.g. from arable to grassland). These more general components are structured separately.

The work in this Activity was completed by developing a complete component breakdown for all the enterprises in Table 3.2.2.

3.2.3. Activity 1.3. Review of literature to aid the creation of the knowledge base

A general literature review was undertaken to identify information that would help identify the structure of the knowledge base for the 'tentative' model and aid its creation.

Six greenhouse gases (GHGs) are covered by the Kyoto Protocol: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Each has a different potential to cause global warming (typically measured over a 100 year period), standardised on a single scale as equivalent tonnes of CO_2 (t CO_2e), its global warming potential (GWP). National inventories (e.g. Jackson *et al.*, 2009) have identified agriculture as a key emitter of N_2O and CH_4. Carbon may be released as CO_2 or stored (sequestered) in soil and plant biomass.

3.2.3.1. Carbon

Fossil fuels are a finite resource and their combustion is responsible for the emission of GHGs, mainly carbon dioxide. Within agricultural systems fossil fuels are used for the operation of farm machinery to conduct operations such as soil tillage and agro-chemical application (Donaldson *et al*., 1994; Hülsbergen and Kalk, 2001; Hunt 1995; Williams *et al*., 2006). They are used for the manufacture of agro-chemicals (Brentrup and Pallière, 2008; Green, 1987; Pimentel, 1980) and farm machinery and for the transportation of such products to the farm. The fossil energy consumed in crop production depends on the number and type of farm operations (e.g. depth of tillage, number of passes, engine size and forward speed of the machine) and the quantity of agro-chemicals, N fertiliser in particular, applied. This is dependent on the crop grown. High N demanding crops such as vegetables tend to have larger emissions than arable crops (Lillywhite *et al*., 2007). Crops that use polyethylene covers with steel supports (e.g. strawberries) are also energy intensive (Warner *et al*., 2005) as are heated greenhouse crops that may also require atmospheric CO_2 enrichment. Fuel consumed during the transportation of produce, crop drying, processing and refrigeration contribute to the GHG emissions of a commodity post farm gate.

Carbon is present in soils as soil organic carbon (SOC) and may be lost when subject to frequent cultivation, a general requisite of crop production. Cultivated agricultural land typically has smaller quantities of carbon in soils and biomass than other forms of land use such as permanent grassland or woodland (Bradley *et al*., 2005; Dyson *et al*., 2009; Smith *et al*., 2008a). A significant potential source of CO_2 emissions is from agricultural peat soils (Schils *et al*., 2008). Peat forms under wet anaerobic conditions. These conditions also continue to prevent the large amounts of C contained within peat from decomposition and release of the C as CO_2. The loss of anaerobic conditions through land drainage results in aerobic soil conditions, decomposition of the peat and the release of CO_2 (Jackson *et al*., 2009; Schils *et al*., 2008). The emission of CO_2 from drained peat may be substantial. Drained lowland and upland peat releases an estimated mean of 10.9 and 7.3 t CO_2e $ha^{-1}year^{-1}$ in the UK respectively (Jackson *et al*., 2009). The loss of CO_2 from cultivated peat soils may be greater, estimated as 15.0 t CO_2e $ha^{-1}year^{-1}$ by Freibauer (2003). The preservation of peat soils may be achieved by prevention of drainage / maintenance of the water table. The impact of restoration on CO_2 loss from peat soils is more uncertain. Freeman *et al*. (2001) report that the phenols that prevent peat decomposition are destroyed when the soil is drained. Decomposition and emission of CO_2 continues after restoration of the water table in response to the 'enzyme-latch effect'. The desired impact of re-flooding peat soils may not therefore be immediate.

Land management that either increases the rate of C accumulation from photosynthesis or reduces the return of C to the atmosphere from combustion or respiration offers opportunity to enhance the C storage of land (Smith *et al*., 2000 a & b). Carbon sequestration is the process of accumulating C in vegetation and soils in terrestrial ecosystems and thus removing (sequestering) it from the atmosphere. One potential route is through a permanent change in land use (e.g. cultivated land to forest). In the context of greenhouse gas inventories this process comes under the title of 'Land Use, Land Use Change and Forestry' (LULUCF), subject to reporting and technical guidance by the IPCC (IPCC, 2000, 2003 and 2006). The IPCC (2006) provides technical guidance in the 'Agriculture, forestry and other land use' (AFOLU) chapter. Activities reported and voluntarily accounted in the LULUCF sector focus mostly on forestry related practices. Soil practices in agriculture ('cropland management' and grazing land management') can be accounted for by countries that have voluntarily elected these activities. Only Denmark and Portugal have elected both, while Spain elected 'cropland management'. The LULUCF sector has been reported to offer the possibility to offset GHG emissions (Brooker and Young, 2005) cost effectively (van Minnen *et al*., 2008;

Songhen and Mendesohn, 2003) by increasing the removal of greenhouse gases from the atmosphere (e.g. by planting trees or managing woodlands), or by reducing emissions (e.g. by curbing deforestation). Van Minnen *et al*. (2008) however consider opportunities in northern Europe to be fairly limited. Further, there are drawbacks as C may be unintentionally released into the atmosphere if a sink is damaged or destroyed through fire or disease. Death of plant biomass results in its decomposition and the release of CO_2 which is rapid in the case of fire.

Carbon sequestration may be achieved through a second route that does not involve a change in land use, rather a change in management within an existing land use. Gains in overall C tend to be lower since the increase in SOC is not as great as a permanent land use change and the change in plant biomass is negligible, if any (i.e. cropland remains as cropland). Such strategies are of relevance to cultivated land as there may be opportunities to improve the SOC content (e.g. more frequent incorporation of organic materials) without loss of production, or even a potential increase in yields. When plant material is returned to the soil it contributes to the soil organic matter (SOM) and SOC content. It may be present in varying stages of decomposition; as fresh material, residue, decaying compounds or stabilised organic matter (Schils *et al*., 2008). Soils do not however increase in SOM and SOC indefinitely (Johnston, 2008). Decomposition of plant material within soil releases C as CO_2. Eventually, equilibrium within the soil is reached when the rate of C added equals that released as CO_2. The quantity of OM and SOC at a given moment in time (i.e. when at equilibrium) results from soil management (e.g. frequency of tillage), soil type (namely percent clay content) (Loveland and Webb, 2000), climate (temperature and rainfall) and type of vegetation cover. Continued addition of C to the soil after the equilibrium has been reached will not increase SOC levels further but will continue to release CO_2 (Johnston, 2008). The majority of change in SOC on cultivated land occurs within top 30 cm (the zone of disturbance) (Smith *et al*., 2000 a and b) and so potential increases in SOC are generally limited to the top soil layers.

Reviews of opportunities for C sequestration in European agriculture have been undertaken by Conant *et al*. (2001), Schils *et al*. (2008) and Ostle *et al*. (2009). More country specific studies include Bradley *et al*. (2005), Dyson *et al*. (2009), Falloon *et al*. (2004), King *et al*. (2004) and Smith *et al*. (2000abc). Strategies common to these studies include reduced frequency of soil tillage and incorporation of organic matter (crop residues, farmyard manure, and straw). On grassland improvements such as fertiliser, liming and mixed swards that contain N-fixing legumes increase the rate of C sequestration (Conant *et al*., 2001; Follett *et al*., 2001; Ogle *et al*., 2003; Soussana *et al*., 2004). Any management improvement that results in an increased rate of growth also results in an increased rate of SOC accumulation (IPPC, 2006). Increasing plant biomass through reduction in grazing intensity (Smith *et al*., 2000a and b; Falloon *et al*., 2004) and planting woodland (Smith *et al*., 2000a and b; Falloon *et al*., 2004; Ostle *et al*., 2009) are further opportunities.

Just as a change in land use may increase the C sequestered, it may have the opposite effect if e.g. deforestation occurs (Jackson *et al*., 2009; King *et al*., 2004; Milne and Mobbs, 2006; Smith, 2005; King *et al*., 2005). This is of pertinence where land managed to increase levels of SOC is reverted to the original method of management. Any potential gains in SOC will be lost and in all probability at a faster rate than it was gained (Smith, 2004). Opportunities to increase SOC come with the caveat that the management must be continued indefinitely. Further, it must also be ensured that management that facilitates C sequestration does not increase emissions of N_2O or CH_4 as these may continue after the new C equilibrium has been attained and accumulation of C ceased.

3.2.3.2. Nitrous oxide (N_2O)

Nitrous oxide has a GWP of 298 t CO_2e hence emission of small quantities contribute significantly to the overall CO_2e emissions of a crop or livestock system. Emissions occur from soil, housing of livestock, manures and grazing deposition (Abberton *et al*., 2008; Jackson *et al*., 2009; Moorby *et al*., 2007; Smith *et al.,* 2008a). In soils emissions are mainly due to microbial nitrification (oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) under aerobic conditions) and denitrification of NO_3^- to mainly dinitrogen (N_2) under anaerobic conditions (Machefert *et al*., 2002). In both reactions a proportion of the N is converted to N_2O however this proportion is larger when denitrified (DeVries *et al*., 2003) and even greater on peat soils. The water filled pore space (WFPS) is a chief determinant of which process is favoured. In general, below 55% WFPS emissions are predominantly from nitrification although both processes may occur simultaneously at WFPS above this percentage. The exact quantity of N_2O released from soils is difficult to predict, subject to uncertainty and highly variable both temporally and spatially i.e. dependent on the time of year and site-specific variation (Machefert *et al*., 2002). It is also stimulated in response to soil temperature because it is a microbial process (Dobbie *et al*., 1999; Dobbie and Smith, 2001; Smith *et al*., 1996). Different agro-climatic regions within Europe have different annual precipitation patterns and variations in soil type that in combination with land management strategies, impact on the emissions of N_2O-N from agricultural land. Machefert *et al*. (2002) and Freibauer (2003) have undertaken an extensive assessment of N_2O from European agricultural soils in a number of Member States. Other more country specific analyses include for example Brown *et al*. (2002), Dobbie and Smith (2003) and Clayton (1997).

The WFPS of soil on a farm is in part, impacted by soil type and recent rainfall (Machefert *et al*., 2002; Smith *et al*., 1996) i.e. the local site environment. Soil type and rainfall are beyond the control of the farmer. Management practices such as the N fertiliser regime and those that impact on soil drainage are however under anthropogenic influence and also key determinants in the magnitude of soil N_2O emission (Bouwman, 1996; Dobbie and Smith, 2003; Smith *et al*., 1996; Tzilivakis, 2005a). Plants utilise N as NH_4^+ and NO_3^- although preference tends to be temperature dependent (Abberton *et al*., 2008). Nitrate does not readily bind with soil colloids and is easily removed (leached) from the soil profile by excess flow of water from for example, heavy rainfall. A mean 1% of N leached forms N_2O (Jackson *et al*., 2009). Nitrogen is necessary for crop growth, however when available N exceeds that needed by the plant the surplus is vulnerable to denitrification, leaching or run-off (Machefert *et al*., 2002; Oenema *et al*., 2005; Smith and Conen 2004; Smith *et al*., 2008a). Other management of importance includes the incorporation of plant biomass (e.g. crop residues), presence of legumes (e.g. clover) and use of irrigation (Abberton, 2008; Smith *et al*., 2008a).

On grassland N is applied as grazing deposition in addition to fertiliser. Quantity is dependent on the type of stock, the proportion of the year the animal remains outside, stocking rate and diet (Abberton *et al*., 2008; Moorby *et al*., 2007). Less intensive grazing systems result in a reduced rate of N ha^{-1} applied as grazing deposition and the risk of overlap between urine patches. This results in decreased N leached, decreased risk of poaching and denitrification and a decline in emissions of NH_3 due to the greater N efficiency of farms (ADAS, 2007b). Avoidance of overgrazing and poaching helps prevent soil compaction and the risk of anaerobic soil conditions. Emissions from the handling and storage of livestock manures depends on the method of storage, how long it is stored and the content of the diet and efficiency with which the N is utilised (Abberton *et al*., 2008; Freibauer, 2003; Jackson *et al*., 2009; Moorby *et al*., 2007; Williams *et al*., 2006).

3.2.3.3. Methane (CH_4)

The decomposition of organic material under anaerobic conditions results in the production of methane (Freibauer, 2003; Smith *et al*., 2008a). Such conditions arise in waterlogged soils, in the rumen of livestock during fermentation of ingested plant material or in manures stored as e.g. slurry (Freibauer, 2003; Mosier *et al*., 1998; IPCC, 2006). The most significant methane losses are from enteric fermentation in ruminant livestock and from manures (IPCC, 2006; Williams *et al*., 2006) although some is also lost directly from flooded soil, an attribute of rice crops.

Livestock farming and, in particular, dairy enterprises are the largest agricultural source of CH_4 in Europe (Weiske, 2006). Enteric fermentation by methanogenic bacteria in ruminant animals emits CH_4. It is dependent on animal type, stocking rate and diet (Abberton *et al*., 2008; Freibauer *et al*., 2003; Moorby *et al*., 2007; Smith *et al*., 2008a). Methane is emitted during storage of both liquid and solid manure although in greater quantities from the former (Freibauer, 2003). The method of manure storage, temperature and source (animal type) are key drivers in determining the rate with which CH_4 is emitted (Monteny *et al*., 2006; Sommer *et al*., 2007). An evaluation of the contribution of the livestock sector to GHG emissions in Europe is currently in progress and due for completion in 2010 (EC DEG Agriculture, 2009).

Rice cultivation is a significant producer of CH_4 and the main cause of CH_4 emissions from agriculture that does not involve livestock. In Europe however rice cultivation is minor and the contribution of this sector to EU agricultural GHG emissions overall is small (COGEA, 2009; Leip and Bocchi, 2007). Methane emitted from non-flooded soils i.e. arable systems, grassland and woodland is negligible (Smith *et al*., 2000a, b & c; Falloon *et al*., 2004; Freibauer, 2003). On aerobic soils oxidation of CH_4 occurs resulting in net removal of C (Freibauer *et al*., 2004). This is enhanced by a reduction of N fertiliser and is a potential benefit of land conversion from cultivated land to grassland or woodland although the restoration of the oxidation process may be subject to a time lag (Paustian *et al.* 2004).

3.2.3.4. Ammonia (NH_3)

Although not a GHG itself a mean 1.0% of the NH_3 volatilised forms N_2O-N (Jackson *et al*., 2009). Ammonia volatilisation tends be problematic when slurry is surface applied in combination with warm air temperatures, for example grassland in the summer (Chambers *et al*., 1999). Sources of ammonia (NH_3) within agriculture include volatilisation from manure applied to land and during storage, urine deposition from grazing animals, and from the urine and faeces of housed livestock. Losses may be influenced further by local factors such as the soil type, the timing and method of manure application, and wind speed.

3.2.3.5. Aerosols

Aerosols are formed in smoke during burning of, for example, vegetation. Although the effect may be either positive or negative with respect to radiative forcing, the overall effect is deemed positive with a net warming effect upon the atmosphere (Smith *et al*., 2008a).

3.2.3.6. Albedo effect

Removal of vegetation may create a dark coloured surface that absorbs greater quantities of short-wave radiation from sunlight making it more prone to warming (Ostle *et al*., 2009). On high C containing peat soils this may increase the rate of CO_2 released due to the drying out of the peat and subsequent oxidation of SOC.

3.2.3.7. Displacement of production

Where mitigation strategies require the removal of land from production, or a reduction in production, this risks the displacement of that production outside of the EU. Continued demand for agricultural commodities (due to low elasticity of demand) is likely to shift production elsewhere, which potentially increases GHG emissions through intensification and/or expansion of agriculture (land-use change) and emissions from increased transportation distance. Mitigation strategies on agricultural land need to account for impact on production and to minimise GHG emissions per tonne of yield. Emission reductions leading to reduced output can only be evaluated if the indirect effects are considered.

3.3. Task 2: On-farm mitigation actions

Activity Start Date	M1	Activity Finish Date	M3
Milestones and Deliverables	Consultation exercise and Phase 1 case studies		
Key project partners involved	University of Hertfordshire and sub-contractors		

3.3.1. Activity 2.1. Literature and data review

A comprehensive literature and data review supported the development process of the 'tentative' model, which, in combination with the farm case studies and consultation exercises, defined the model requirements, and provided actual examples of agricultural GHG mitigation actions that may be implemented within the EU. The review included on farm emissions (to the farm gate) from fuel consumption (spraying or spreading, irrigation, tillage operations and drilling, heating and lighting of livestock housing and glasshouses, crop drying), emissions from soil (CO_2, N_2O and CH_4), livestock (enteric fermentation, manures and their storage), and considered potential impacts on C in soil and plant biomass. It also included upstream emissions from product manufacture (pesticides, fertilisers, polyethylene for polytunnels and mulch, their packaging, storage and transport to the farm) and machinery manufacture (based on depreciation per operation).

3.3.1.1. Livestock: Enteric fermentation

Enteric CH_4 production correlates with the ease that the animal is able to digest feed; the slower the rate of digestion (i.e. the lower the digestibility) the greater the volume of CH_4 produced (Duncan, 2008). The replacement of roughage from forage crops with a greater proportion of feed concentrate results in a decrease in CH_4 per MJ of dietary energy, per kg of feed intake and per kg of product (Beauchemin *et al*., 2008; Johnson and Johnson, 1995; Lovett *et al*., 2006; Mills *et al*., 2003; Smith *et al*., 2008a; Yan *et al*., 2000). Starch is the fermented substrate as opposed to fibre while the pH in the rumen decreases. An increase in the starch or soluble carbohydrate dietary component enhances propionate formation which reduces the available hydrogen to form CH_4 (Monteny et al., 2006). Further, recent although not totally conclusive evidence suggests that the type of forage crop is also of relevance (Beauchemin *et al*., 2008). Preliminary findings suggest that maize and cereal silage stimulates less enteric methane than grass silage. Both maize and cereal silage contain greater quantities of starch than grass silage (Thomas, 2004). Schils *et al*. (2007) cite increased hectarage of forage maize to reduce grazing intensity as a mitigation strategy. Deposition of N is also reduced however CH_4 from manures increased (anaerobic digestion would eliminate this) due to longer housing periods. Substitution of grassland with maize requires cultivation of potentially uncultivated land (depending on frequency of reseeding) and a loss of SOC. Concentrates typically contain a mixture of grain or oilseeds and are generally imported onto the farm, effectively importing additional N that will ultimately be deposited within the farm system. The emissions associated with their production and transport relative to that of a forage crop must also be included in the overall GHG balance in addition to the impact on CH_4 produced by the animal (Lovett *et al*., 2006; Warner *et al*., 2008ab; Williams *et al*., 2006). It is acknowledged that feed may be imported from outside the EU however precise calculation of emissions may be difficult to quantify. The optimal diet is subject to the breed of animal, projected milk yield and must also account for milk quality. A diet of >50% concentrates has been reported to reduce milk quality (Beauchemin *et al*., 2008) while increased dependency on maize in the diet may risk greater polyunsaturated fatty acid content (Schils et al., 2007). Enteric emission of CH_4 may also be reduced by improvement to the dietary quality of grazing land though inclusion of for example, legumes (Alcock and Hegarty 2005; Waghorn *et al*. 2002). The output of marketable commodity (animal protein or milk) is increased and CH_4 per unit of output reduced in proportion. Lower rates of replacement also reduce enteric and manure emissions per kg of output (McCrabb, 2001).

Recent reviews of near market mitigation strategies and potential impact on enteric CH_4 is given by Beauchemin *et al.* (2008), Monteny *et al*. (2006) and Smith *et al*. (2008a). Dietary additives have also been cited by a number of authors as offering potential to reduce enteric fermentation in livestock. They include:

1. Lipids (oils) increase digestion rate, particularly those high in medium-chain fatty acids (MCFA) (Beauchemin *et al*., 2008; Duncan, 2008; Lovett *et al*., 2003; Machmulller *et al*., 2000, 2003, McGinn *et al.,* 2004; Smith *et al*., 2008a).
2. Halogenated compounds prevent CH_4 production by methanogenic bacteria but the impact may be temporary and livestock productivity may be reduced due to inhibition of feed intake (Van Nevel and Demeyer, 1996; Wolin *et al*., 1964; Smith *et al*., 2008a)
3. Fumarate and malate prevent bonding of hydrogen with the C molecule but commercial practicability is restricted by the high dosage requirement (Beauchemin *et al*., 2008; McGinn *et al*. 2004; Newbold *et al*., 2002 and 2005; Smith *et al*., 2008a; Wallace *et al*., 2005)

Growth hormones that increase productivity (McCrabb, 2001) may decrease emissions per unit of output however restrictions on their use within the EU invalidate them as a realistic option at present and they have not been considered for inclusion within the 'tentative' model. Antibiotics (ionophores), e.g. monensin, have been demonstrated to reduce enteric CH_4 but the effect may be temporary (Beauchemin *et al*., 2008; Smith *et al*., 2008a). The use of such products is not permitted within the EU (Smith *et al*., 2008a) and for this reason, they too have not been considered for inclusion. Strategies that may be available in the future include vaccination to prevent development of methanogenic bacteria within the rumen (Wright *et al*., 2004; Smith *et al*., 2008a) and the selection and administration of probiotics specifically for the purpose of methane reduction (Newbold and Rode, 2005; Smith *et al*., 2008a). Such measures are not at present commercially available.

3.3.1.2. Livestock: Nutrient use efficiency

The energy content of feed may be classed as either gross energy (total energy content from combustion), digestible energy (the remaining energy after subtracting the energy lost in faeces) or metabolisable energy (ME) (the digestible energy minus the energy lost in urine) (Thomas, 2004). The formulation of livestock diets must satisfy a required ME and crude protein (CP) content (Williams et al., 2006) in addition to nutrients and minerals. Optimal utilisation of N within the feed consumed by the animal produces amino acids and protein. Nitrogen is removed from the animal in faeces and urine and this will occur even for optimal diets since a proportion of CP is not digested. It may be increased however by intake of excessive dietary protein (and N) (Schils *et al*., 2007). Diets may contain higher than recommended CP requirement as an 'assurance' mechanism to ensure that the CP need is met but could be reduced without reducing output (Moorby et al., 2007). A proportional reduction of dietary N intake relative to output (i.e. incorporation into animal protein) improves the efficiency of N utilised by the animal and reduces the environmental loss of N as grazing deposition (Kulling *et al*., 2003) and from housing and manure storage (Moorby et al., 2007; Schils et al., 2007). Different feeds contain different quantities of CP per unit of ME. As a result the satisfaction of the ME requirement combined with optimal intake of CP depends on the type and quantity of feeds consumed (assuming other needs such as minerals are also satisfied). The proportion of other feed components (e.g. starch) also exert an influence since the rapid digestion of protein but failure by rumen bacteria to incorporate it (a result of lack of 'readily available energy' during the breakdown of vegetable protein due to dietary imbalance) also increases the excreted N (Abberton *et al*., 2008; Dewhurst *et al*., 1996). Diets that contain a greater proportion of starch (e.g. maize) have been found to reduce the quantity of N within urine (Kebraub *et al*., 2001; Schils *et al*., 2007). Other mitigation strategies include enhancement of readily available energy when fermentation begins and feeds with reduced protein availability to slow the rate of breakdown by rumen bacteria (Abberton *et al*., 2008). Such strategies must be carefully balanced with increased enteric fermentation. Dietary composition must also account for genetic potential (i.e. breed), age, sex and production stage. The use of growth hormones to improve productivity reduce emissions per kg of output (McCrabb, 2001) however as stated previously, restrictions on their use within the EU invalidate them as a realistic option at present.

When livestock are grazed, N is deposited onto grassland in urine and faeces (IPCC, 2006). The higher the stocking rate, the greater the probability that the same patch of ground will receive several doses of urine, and greater concentrations of N. Such areas are vulnerable to N loss as leaching of NO_3^-, denitrification of N_2O and volatilisation of NH_3 (ADAS, 2007b). A reduction in stocking rates or the housing of livestock indoors for a proportion of the year (i.e. less intensive grazing systems) result in a reduced rate of N ha^{-1} applied as grazing deposition, which reduces the risk of overlap between urine patches and therefore multiple doses of N. A consequence is decreased N leached, decreased risk of poaching and denitrification and a decline in emissions of NH_3 due to the greater N efficiency of farms (ADAS, 2007b). Where overgrazing and poaching is avoided the loss of biomass within grass is also prevented because the sward is taller or there is reduced incidence of bare soil patches. The housing of livestock during the winter has been cited as a potential mitigation strategy since deposition of N onto grassland during periods of greater daily rainfall and when the grass is not growing and utilising N is also avoided (Moorby *et al*., 2007, Schils *et al*., 2007). This is however dependent upon the climate and winter rainfall. The housing of livestock increases the quantity of manure produced, with associated GHG emissions that must be accounted for, the magnitude of which are dependent on the method of manure storage (section 3.3.1.3.). Housing also reduces the grazing period and the proportion of grass in the diet which, depending upon other dietary components, may reduce enteric fermentation. Implications for decreased milk quality through an increased polyunsaturated fatty acids component have also been noted (Schils *et al*., 2007) but this is dependent upon the proportion of other dietary components (e.g. concentrates). Outdoor grazing is also needed for the maintenance of permanent grasslands, thereby benefiting biodiversity, soil and watershed protection. The housing of livestock must be carefully balanced with the need to manage permanent grasslands effectively of which outdoor grazing is a requisite.

3.3.1.3. Livestock: Housing, manure and slurry management

Emission factors of CH_4 and N_2O during the housing of livestock and storage of manures are provided by Chadwick and Pain (1997), Freibauer (2003), IPCC (2006), Jackson *et al*. (2009) and Monteny et al. (2006). Lower emissions of CH_4 are reported from pig housing that use 'tying stalls' as opposed to 'cubicles' (Groot Koerkamp and Uenk, 1997). Monteny et al. (2006) cite regular and complete manure removal from indoor storage pits (in combination with appropriate storage) as a further means to reduce CH_4 emissions from housing. Methane is produced by the storage of manure as slurry in response to a combination of anaerobic conditions and high organic content (Monteny, 2006). The temperature at which the slurry is stored impacts the rate of CH_4 production with cooler temperatures decreasing the rate of production. Emissions are reported as low at temperatures of 15°C or below (Monteny, 2006). Artificial cooling (Monteny, 2006) and the covering of storage tanks and lagoons (Paustian *et al*., 2004) are potential mitigation strategies. Methane produced from slurries and manures has valuable potential to replace fossil fuels. Banks *et al*. (2007) report that anaerobic digesters capture 350-450 m^3 CH_4 t^{-1} organic dry matter for use as fuel that would have potentially otherwise have been released into the atmosphere.

Nitrogen may be lost during storage as solid manures since they contain both aerobic and anaerobic micro-sites where NH_4^+-N can be nitrified to NO_3^-, providing a source of N_2O emission by denitrification (Monteny et al., 2006). Avoidance of anaerobic micro-sites in animal bedding also prevents denitrification (Schils *et al*., 2007). Loss of N during storage is an inefficient use of N that may otherwise be utilised by the crop and potentially substitute inorganic fertiliser N. Where strict anaerobic conditions in manures are maintained nitrification and denitrification are usually inhibited (Monteny et al., 2006). The introduction of straw during housing (e.g. bedding) aerates manures sufficiently to allow nitrification and denitrification to proceed (Groenestein and Van Faassen, 1996). Converting from a solid manure based system to one that is slurry based potentially reduces the likelihood that slurry NH_4^+-N is converted into NO_3^- until spread, subject to anaerobic conditions being maintained (Monteny et al., 2006). In a slurry tank the only area where aerobic conditions exist are the slurry-air interface on the upper surface and formation of N_2O is increased in response to increased surface area of this part of the store (Schils *et al*., 2007). A reduction in surface area reduces the risk of N_2O emissions. A negative impact of slurry based systems is that emissions of NH_3 are increased in addition to those of CH_4 (Moorby et al., 2007). Its overall effectiveness may be enhanced if used in combination with measures to mitigate emission of CH_4 described in the previous paragraph. Where options are limited to a solid system the covering of manure heaps may reduce emission of N_2O (Chadwick, 2005). Another strategy and one that is employed widely by organic farmers is the composting of manure (Williams *et al*., 2006). It has potential to provide N in a more readily available format for plant uptake that may substitute greater quantities of inorganic N relative to the energy used for its application.

Where the housing of livestock does not occur, for example in warmer climates, manure is solely in the form of grazing deposition. Grazing deposition of N tends to be more random in its distribution and not easily controlled (Oenema *et al*., 2005) although lower stocking rates reduce the risk of excessive deposition of N (which then decreases the risk of emission of N_2O) in any one location (ADAS, 2007a). The constant relocation of water or feeding troughs prevents continued deposition in any one area and, more importantly, the deposition of large quantities of N onto compacted soil (due to continued trampling by livestock) where anaerobic soil conditions may persist.

Fuel/energy is also consumed for heating, lighting and ventilation in livestock housing, so there is some scope for mitigation here through increased energy efficiency. These aspects are reviewed in Section 3.3.4.2.

3.3.1.4. Cropping: Crop nutrition

Nitrate not utilised by the crop through excessive application or poor timing does not remain within the soil and is at risk to leaching or denitrification. Further, the manufacture of inorganic N fertiliser, nitrate fertiliser in particular, is also responsible for the emission of GHGs (Jensen and Kongshaug, 2003) and any loss of N from the crop requires replacement with additional inorganic N. A number of authors identify good fertiliser practice that ensures crop N requirements are not exceeded and that the time between application of N and uptake by the crop is minimised as an effective means of reducing agricultural GHG emissions (Cole *et al*., 1997; Powlson *et al*., 1986; Moorby *et al*., 2007; Paustian *et al.,* 2004; Smith *et al*., 2008a). This is applicable to 'developed' agricultural systems that are near having achieved their full yield potential (Oleson and Bindi, 2002; Hillier *et al*., 2009). Recommendations that account for the soil nitrogen supply (SNS) index (e.g. MAFF, 2000) take account of existing soil N levels and adjust application rates accordingly to prevent over fertilisation. They also account for the N, P and K in livestock manures. Regular soil tests to determine N content is another option (although at a cost to the farmer). Following such recommendations is an effective means of mitigating GHG emissions without loss of yield. Uneven or inaccurate spreading of fertilisers and manures has been found to increase the risk of nitrate loss compared with accurate spreading (ADAS, 2007a). Avoidance of broadcast application also reduces risk of over application while banding (N placement) is a more efficient fertilisation technique in row crops. Further improvements to efficiency may be made through more wide scale adoption of precision farming (Moorby *et al*., 2007). It is important that mitigation strategies seek to optimise input use i.e. under-fertilisation of crops may cause a yield reduction greater in proportion than the reduction in GHG emissions with a net increase in emissions per unit of crop output. Some regions of the EU (namely the Continental regions / new MSs) are subject to a 'yield deficit', that is they are not reaching their full potential yield and this could be addressed through improvement in agronomic practices (Oleson and Bindi, 2002). Such regions will benefit from more optimal fertiliser use to increase crop yields as a GHG mitigation strategy (Hillier *et al*., 2009).

The application of slow-release fertiliser products or coated fertilisers allows gradual release of N simultaneously with crop uptake. Accumulation of surplus NO_3^- within the soil is restricted which reduces emission of N_2O from leachate or run-off. Decision Support Tools (DST) may assist the planning of quantity and timing of fertiliser N but will be highly site specific. There are also techniques that have not yet been fully validated. For example, a substantial proportion of the N_2O emissions from productive agriculture results from the nitrification and denitrification of mineral N fertiliser applications that are made to soils periodically during the growing period. Such emissions are very 'event driven' in that high emissions typically occur only during a small number of days when applications concur with wet and warm conditions in the soil. A small moisture deficit immediately preceding N application coupled with average rainfall during the spring has been found to increase N loss (Powlson *et al*., 1986). Goulding *et al*. (2006) concluded that denitrification rates from soils to which inorganic N fertiliser had been applied were greatest four days after heavy rainfall. If such events could be avoided then large reductions in emission may be achievable. Avoidance might be possible using soil tests and/or weather forecasts. Another example is the use of nitrification inhibitors, which are chemicals that reduce the rate of conversion of NH_4^+ to NO_3^-. The rationale is that the rate of nitrification is reduced so that NO_3^- is formed at a rate that the crop can use (i.e. slow release), increasing N efficiency and reducing N_2O emissions and NO_3^- leaching. Grass buffer strips help prevent surface flow of NO_3^- into water courses, the effectiveness increasing with greater buffer strip width.

Manures from livestock contain N. The proportion of N that is available to the crop is dependent on the timing and method of its application (MAFF, 2000). Increasing the efficiency of manure N applications has also been highlighted as a key measure (Moorby *et al*., 2007) as it can further substitute manufactured inorganic fertiliser N. Optimal timing (so that N availability is simultaneous to crop growth) and application techniques (for example deep injection of slurry) reduce environmental loss to leaching and volatilisation of NH_3 (MAFF, 2000). Avoiding application of manures close in timing to inorganic fertiliser N may help reduce the risk of increased denitrification. Further, growing leguminous crops (e.g. by undersowing) provide the opportunity to partially substitute N fertiliser. Legumes offer significant potential on grassland and may eliminate the need for inorganic or organic fertiliser altogether (King *et al*., 2004). Legumes release N_2O while fixing N, the quantity dependent on the species and plant density (Cuttle, 2003; Rochette and Janzen, 2005). On cultivated land undersowing a crop with a legume permits release of N during crop growth but does not remove land from production for a year as the case would be for a ley. Leaching of N from legumes in grassland has been reported as similar to grassland fertilised with 200 kg N ha^{-1} (Abberton *et al*., 2008) however this may be remedied in part via genetic improvement.

3.3.1.5. Cropping: Water and irrigation

The application of water to croplands via irrigation is an energy intensive process (Dalgaard *et al*., 2001; Mosier *et al*., 2005). Strategies that reduce the need for irrigation will be particularly relevant to mitigating GHG emissions in the southern agro-climatic regions. They include soil management that enhances the water holding capacity of soils (for example through an increase in soil organic matter (SOM), or improved infiltration in response to increased pore space), reducing soil evaporation (leaving residues on surface, minimum tillage), irrigation of crops only at the most sensitive stages in growth, maximising water extraction by the crop roots (through deeper tillage to improve rooting depth), minimising / eliminating soil drainage, coupling crop production with seasonal rainfall patterns and use of drought tolerant crop varieties (Debeake and Aboudare, 2004). Other methods to optimise application include scheduling and systems with greater efficiency (e.g. trickle irrigation) (Sakellariou-Makrantonaki *et al*. 2007). Partial root zone drying, where only the upper proportion of the crop root zone is irrigated, is a relatively new strategy that has also demonstrated potential. Water sensors may be used to control irrigation such that the desired soil water capacity (usually field capacity) is not exceeded reducing the risk of nitrate leaching and denitrification. Inter-cropping (two different crops grown adjacent to one another in rows), multi-cropping and relay cropping may also enhance the efficiency of water use (Kromm and White, 1990) as does flush irrigation or alternate wetting and drying of rice crops (Smith *et al*., 2008a). General maintenance includes using the correct sized pump and hose length for the depth of water to be abstracted and distance pumped (CALU, 2007).

Mains water treatment is an energy intensive process (Wessex Water Ltd, 2004) and use of 'grey water' (untreated water) as an alternative will also significantly reduce the GHG emissions associated with crop irrigation. Mitigation strategies therefore include means by which to collect rainwater such as the construction of reservoirs or the use of gutters to collect rainfall run-off from greenhouses and polytunnels for subsequent use in irrigation. Desalination is also an energy intensive process and widely used in southern European countries.

3.3.1.6. Cropping: Machinery use and field operations

The number of passes and machinery operation time per ha may be reduced by increased width of implement (Hunt, 1995) however this must be balanced with increased risk of wheel slip above 15% (CALU, 2007). Reduced cultivation depth reduces energy consumption, particularly on heavy soils (Kalk and Hülsbergen, 1999). Deeper and more energy intensive tillage operations such as subsoiling may be targeted to areas most at risk of compaction, namely the tramlines (Williams *et al*., 2006). One-pass machinery that combines multiple field operations into one reduces fuel consumption and embodied emissions in machinery depreciation. The scrapping of old and inefficient machines, where obsolete, has also been cited but incurs a long payback investment.

A number of general maintenance and good practice measures may be adopted on farm to optimise the energy consumed by farm machinery (CALU, 2007). These include using recommended tyre size and pressure to reduce rolling resistance, ensuring the power of the tractor is correlated to the type of operation (i.e. not overpowered), not cultivating under adverse conditions (prevents the need for additional field operations), use of ballast to reduce wheel slip / ensure wheel slip is 10-15% for optimal traction, optimal combination of gear and engine speed when undertaking operations with a large draught and ensuring the tractor is serviced according to manufacturers guide.

3.3.1.7. Cropping: Post harvest operations

The drying of grain may be an energy intensive process (Williams *et al*., 2006) but techniques such as appropriate harvest management to ensure grain is at optimal moisture content, the use of high air volumes (0.05 $m^3\ s^{-1}\ t^{-1}$ grain dried), use of recirculation or mixed flow drier, accurate measurement of grain moisture content, and dry or low rate aeration offer opportunity for significant energy savings (CALU, 2007). The solar drying of crops has been cited as a further alternative to reducing energy consumption (Smith *et al*., 2008a) although its viability will depend on the climatic zone.

The storage of potatoes and fruit within a controlled atmosphere (CA) is another energy intensive process although consumption depends on the time of year and external air temperature (Mila-i-Canals, 2007; Williams *et al*., 2006). Recommended methods to reduce energy consumption (CALU, 2007) include: increased store insulation, use of automated control, frequent checking of sensor accuracy, prevention of air leakage within the system, and appropriate size of fan. The growing of new apple varieties (for example Meridian) that may be available in northern agro-climatic regions without the need for CA storage until January reduces the time apples are in CA storage and the need for imports.

3.3.1.8. Cropping: Covered and container grown crops

The protection of vegetable or fruit crops with polyethylene polytunnels or mulch may incur significant energy use and emissions for their manufacture (Warner *et al*., 2005). Polytunnels are used to protect crops such as strawberries from frost (in early crops produced out of season) or rainfall during fruit set when damage to the flower causes misshapen fruit. They allow production of fruit earlier in the season and the sequential planting of crops. Maximising the life-time of such products i.e. reuse as far as possible can make significant reductions to the overall CO_2e during production of the crop.

Container grown fruit and vegetable crops or hardy nursery stock may use peat as a growing substrate. The extraction of peat causes loss of sequestered C. 'On-site' emissions of CO_2 result from the peatland in response to extraction in combination with 'off-site' emissions from the extracted peat used in growbags (Jackson *et al*., 2009) and its use as a substrate is not sympathetic with mitigating agricultural GHG emissions. An alternative growing media is coir fibre. This has a high C to N ratio (Abad *et al*., 2002) and causes N immobilisation that renders it unavailable for plant uptake (Wallace *et al*., 2004). Additional N fertiliser is needed to replace the immobilised N that is significant in crops with a low N requirement such as strawberries (Warner *et al*., 2005). Its use for crops with a higher N demand crop may also not be conducive with GHG mitigation. Other alternatives include composted materials.

3.3.1.9. Cropping: Glasshouses

In cooler agro-climatic regions fuel needed for heating is the main source of GHGs. Mitigation strategies typically involve structural modifications to the outer structure (type of glazing, sealing of gaps etc), the use of thermal screens at night and the modification of temperature and humidity set-points (Korner *et al*., 2007). The capture of CO_2 emitted by fuel combusted for heating may be used to enrich atmospheric CO_2. Combined Heat and Power (CHP) may also significantly reduce emissions. In warmer climates cooling is a major consumer of energy. The use of for example shading and evaporative cooling help reduce energy use.

3.3.1.10. Cropping: Rice cultivation

The cultivation of rice is considered within its own category by the IPCC (2006) since the decomposition of organic material under anaerobic conditions such as those found in rice cultivation causes emission of CH_4. A small area is devoted to rice production in the EU and consequently it does not make a major contribution to agricultural GHG emissions in Europe (COGEA, 2009). A number of mitigation strategies have been proposed, many of which centre on the creation of aerobic soil conditions during the year through intermittent drainage, incorporation of residues (preferably composted prior to application) in dry conditions and the avoidance of waterlogged soil conditions post production (Smith and Conen 2004; Xu *et al*., 2000; 2003; Yan *et al*. 2003).

3.3.1.11. Cropping: Cover (or catch) crops

The impact of cover (or catch) crops on N loss by leaching, and the indirect N_2O emissions that result from leachate (Jackson *et al*., 2009) is difficult to predict, and subject to significant uncertainty due to the number of site specific variables such as winter rainfall, existing soil N content and soil type (MAFF, 2000). They are reported to reduce N leaching typically by between 25 and 50 kg N ha^{-1} (Silgram and Harrison, 1998), however this figure must be treated with caution because of the site specific factors described previously. Cover crops also prevent loss of soil from wind erosion (Duncan, 2008) and the nutrients and C contained within that soil. They also prevent the growth of weeds and so may nullify the emissions from the additional herbicide required for their destruction. The mineralisation of crop residues after the destruction of the cover crop will also result in additional N_2O emissions (Jackson *et al*., 2009) however C is added to the soil (Freibauer *et al*., 2004). A reduction in the N leached of between 5 and 10 kg N ha^{-1} was predicted by Warner *et al*. (2008) not to increase GHG emissions overall, less than the typical value achieved (Silgram and Harrison, 1998).

3.3.1.12. Cropping: Pest, weed and disease control

All manufactured inputs (pesticides, fertilisers etc.) require energy during their manufacture. The primary energy consumed during pesticide manufacture is estimated to be 67 MJ kg^{-1} of active ingredient (ai) (halogenated hydrocarbons) and 460 MJ kg^{-1} ai (paraquat) (Pimentel, 1980; Green, 1987). This excludes packaging, storage and transport equivalent to 23 MJ kg^{-1} of ai (Hülsbergen and Kalk, 2001). The manufacture of crop protection products consumes fuels in the following proportions: 40% electricity, 22% natural gas, 5% fuel oil and 33% naptha (Green, 1987). Crop protection makes relatively minor contributions to the overall GHG balance in many crops due to small quantities of active ingredient (Hülsbergen and Kalk 2001; Tzilivakis *et al.*, 2005a, b) and as such has received relatively minor attention with respect to agricultural GHG mitigation. An exception is soil fumigants, used in crops such as strawberries, which are applied at 200-400 l ha^{-1} with between 94 and 100% active ingredient (Lainsbury, 2009). Fumigation tends to be necessary where soil borne pathogens such as Verticillium wilt are established. The testing of soil for Verticillium and targeting of fumigation as necessary offers potential to reduce the quantity applied without compromising productivity. For an agro-chemical applied in such large quantities there is significant potential to reduce the GHG emissions associated with the crop protection component of fumigated crops. The voluntary withdrawal of chloropicrin due to the review of EU Directive 94/414 means that infected areas require alternative methods of soil sterilisation. These may involve growing of bio-fumigant crops that will themselves have GHG emissions associated with their cultivation. Spatial targeting of synthetic pesticides identifies specific areas within the crop where the pest may be present (for example the perimeter or areas adjacent to known hibernation sites) and applies a treatment solely to that area (Warner *et al.*, 2008c). This reduces the quantity of agrochemical applied and the distance driven by the sprayer, both offering potential to reduce GHG emissions.

3.3.1.13. Carbon: Soil Organic Carbon

Significant quantities of C may be emitted from soils as CO_2. This is of particular relevance for cultivated organic soils, soils that undergo land-use change (e.g. grassland to arable) or if soils are managed inappropriately. Cultivated land has been reported as containing smaller quantities of SOC compared to grassland or woodland on the same soil type (Bradley et al., 2005; Dyson et al., 2009). Key determinants include the frequent disturbance of the soil and smaller returns of plant residues to the soil (Smith et al., 2000 a and b; Falloon et al., 2004). A number of management options have been proposed to increase the SOC of cultivated land without its removal from production. Recent review papers of significance applicable to the EU as a whole and that cite publications from a number of individual Member States include that of Ostle *et al.* (2009) and Schils et al. (2008). Strategies include incorporation of organic materials (farmyard manure, straw, crop residues) into cultivated land, avoidance of burning, a reduction in tillage frequency, prevention of soil erosion and the reduction of drainage on peat soils (Cerri *et al*., 2004; Falloon, *et al*., 2004; Smith *et al*., 2000a,b; Smith *et al.*, 2008a). The majority of disturbance and potential to change the SOC of cultivated land however occurs down to a depth of 30 cm (Smith et al., 2000 a and b). The decomposition of plant material via nitrification and formation of NO_3^- is an inevitable side effect of residue incorporation and a proportion of this will form N_2O (Machefert *et al*., 2002) but may be reduced by strategies to avoid excess NO_3^- within the soil from N fertiliser. Tillage frequency may be reduced by the inclusion of a two year grass clover ley in a rotation, the growing of perennial crops and zero tillage. Minimum tillage uses discs to disturb the top few centimetres of soil allowing accumulation of SOC in deeper soil layers normally subject to disturbance (Smith *et al*., 2000a and b, King *et al*., 2004). Zero tillage does not use cultivation. The net GHG balance of these two strategies requires the inclusion of fuel consumed by machinery (reduced by elimination of the energy intensive soil cultivations) and emission of N_2O (increased by greater soil compaction). Additional emission of nitrous oxide when zero tillage is implemented under wetter climatic conditions eliminates any reduction in CO_2 emission or increased SOC (King *et al*., 2004; Schils et al., 2008). Critically the effectiveness of this technique is dependent on agro-climatic region where N_2O released in dryer climates is similar (Marland *et al*., 2001) or lower in semi-arid conditions than baseline emissions (Helgason *et al*., 2005). Zero tillage is restricted to crops that may be drilled (King *et al*., 2004). In semi-arid croplands the elimination or reduction of summer fallow is a means to increase C and decrease soil erosion (Campbell *et al*., 1990; Janzen, 1987).

Soil carbon may also be increased by conversion of cultivated land to permanent cropping (i.e. untilled land) which is either ungrazed (e.g. woodland, wildlife strips/zones) or pasture with a low stocking rate and zero or low fertiliser inputs. This strategy however raises issue with potential displacement of production (section 2.2.3.7.). Conant *et al*. (2001; 2005) and Freibauer *et al*. (2004) highlight the importance of timing and intensity of grazing on the rate of C accumulation in grassland soils however the variability in grazing management practices in combination with differences in soil type and climate led Smith *et al*. (2008a) to conclude that too great inconsistency existed between studies to recommend with confidence. The application of N to grasslands, subject to Good Fertiliser Practice, to address nutrient deficiency increases productivity and accumulation of SOC (Conant *et al*., 2001). The use of grass species with deep rooting systems may enhance accumulation of SOC although this is unconfirmed (Conant *et al*., 2001; Smith *et al*., 2008a). There are additional benefits from the presence of grass strips in cultivated land subject to location, such as the reduction of soil erosion (Wischmeier and Smith, 1978; Renard *et al*., 1997) and the enhancement of beneficial insects (Warner *et al*., 2008c) with potential to reduce the number of insecticide applications. The prevention of soil erosion reduces loss of SOC and P. Inorganic P has emissions associated with its manufacture and application. Other strategies to prevent soil erosion include the incorporation of organic matter and avoidance of bare soil during the winter (e.g. cover crops).

Soil conditioners, for example biochar, are another potential means to increase soil carbon (Verheijen et al., 2009). Biochar is produced by the pyrolysis (heating in the absence of oxygen) of organic materials, mostly wood and agricultural residues. Its decomposition in soil is thought to be between 10 and 1000 times slower than SOM providing a potential C sink (Verheijen et al., 2009). The effectiveness of biochar is currently uncertain while the impact of different climates and soil management regimes is also poorly understood. Further, preliminary research has suggested that addition of biochar to soils initially increases the rate of SOM decomposition and accelerates the release of CO_2 (Verheijen et al., 2009). Concerns have also been raised about the potential for soil contamination. Inferences drawn on its effectiveness at present have depended on extrapolation of results from a small number of studies conducted over limited temporal and spatial scales. In addition, the GHG impact of the application of biochar can be evaluated only in conjunction with the source of the biomass (impacts of production, potential alternative uses), the conversion technology and the use of by-products. Because of this uncertainty it is not at present recommended as a means to enhance C within soils.

The draining of organic soils for agricultural purposes results in loss of SOC as CO_2. Preservation of high C containing peat soils has been identified as a priority mitigation strategy in countries such as Scotland (Smith *et al*., 2008a) and Finland (Regina *et al*., 2009), and at EU level (Schils et al., 2008; the forthcoming Scenario 2020 report). Peat soils contain greater quantities of SOC at equilibrium than other soil types however this C may be lost to the atmosphere as CO_2 by oxidation within aerobic conditions created by land drainage (Jackson *et al*., 2009; Schils et al., 2008). Management practices that preserve or restore the water table though the blocking of drainage ditches have the potential to prevent the further release of CO_2 (Freeman *et al.,* 2001; Moorby *et al.,* 2007). Such options are restricted by soil type and location and are restricted to the northerly regions the EU. On existing drained organic soils the avoidance of row crops, deep cultivations and maintenance of shallow water tables helps to reduce such losses (Freibauer *et al*., 2004). The term 'paludiculture' has been coined to describe the growing of water tolerant plant species such as reed (*Phragmites* spp) or alder for use as biomass crops on either wet or rewetted peat soils (Wichtman and Joosten, 2007). Biomass production is permitted while the C within peat does not oxidise to CO_2 and accumulation of C may continue.

3.3.1.14. Carbon: Plant biomass

Different habitats reach their potential full biomass after different periods of time. On cultivated land fallow areas contain negligible plant biomass and are not an efficient manner in which to use productive land. They are also subject to loss of residual N (increased risk of N_2O emission) and soil erosion (loss of SOC and P). Avoidance of such land management has been recommended by several authors in both wetter (Freibauer, 2004; Smith, 2004a and b; Smith et al., 2008a) and drier agro-climatic regions (Campbell *et al*., 1990; Janzen, 1987). A similar argument has been made for green cover managed as 'environmental set-aside'. Under certain site specific circumstances however, green cover may be beneficial in reducing run-off into watercourses, preventing soil erosion and enhancement of beneficial insects (e.g. beetle banks).

Hedgerows, a boundary feature more predominant in the UK and Germany (Farmer et al., 2008), tend to be present on existing non-productive areas of the farm. A higher specified minimum height offers potential for a greater quantity of C within plant biomass to be established (Warner *et al*., 2008a). Further opportunity to gain additional C stored within hedgerow plant biomass is provided by a combination of 'gapping up' and the planting of new or restoration of hedgerows. The increase in hedgerow biomass will also have a negligible impact on agricultural production. Other linear boundary features (Farmer et al., 2008) of relevance to increased plant biomass include shelterbelts (lines of trees) (Falloon et al., 2004) to reduce wind and erosion, wooded pastures and agroforestry. A greater quantity of biomass is contained compared to hedges because they are typically greater in height. Again, they are present on existing non-agricultural land although shading may reduce crop productivity on the crop periphery. Grass field margins contain smaller quantities of biomass than hedges (Falloon et al., 2004).

3.3.1.15. Other strategies: Energy crops

Biomass crops offer potential to substitute fossil fuels either as generators of energy (Falloon et al., 2004) or as feedstock for the manufacture of bio-plastics (NNFCC, 2010). The growing of biofuel crops requires inputs of fertilisers and pesticides, and fuel to drive machinery. Further, it results in release of N_2O from soil in response to N fertiliser application, discussed previously. This is crop specific but is higher in crops such as wheat, oilseed rape and sugar beet compared to *Miscanthus* and short-rotation coppice. In the latter crops land is not cultivated annually and mineral N fertiliser requirements are moderately low. A greater quantity of C exists as biomass at equilibrium compared to arable crops, particularly below ground in the roots (Smith *et al*., 2008a). *Miscanthus* and short-rotation coppice have a greater demand for water than wheat or oilseed rape (UNEP, 2009).

The overall impact of energy crops depends on the original land use (St Clair *et al*., 2008) and the risk of displacement of crops for food production onto previously uncultivated land or overseas. The magnitude of GHG mitigation also depends significantly on the type of energy replaced and the efficiency of conversion. Benefits may be realised if grown on existing degraded land (UNEP, 2009) however there is a risk of displacement of food production if grown on productive arable land, which could result in food being imported from outside the EU, possibly with greater GHG emissions. Non-land displacement strategies to produce biofuels include the utilisation of crop residues although removal of crop residues is likely to have negative impacts on soil C levels and crop yields. This in turn has a displacement effect since more land is required to produce the same yield of crop. Other strategies include 'paludiculture' discussed in section 2.3.1.13.

3.3.1.16. Other strategies: Genetic improvement

In theory any improvement to production efficiency (where output is increased relative to inputs or emissions) offers the potential to reduce emissions per unit of commodity. Livestock breeding, for example, to improve longevity (including calving ease for dairy cows), fertility and attainment of slaughter weight at a younger age have fewer emissions per unit of output (Lovett and O'Mara 2002; Smith *et al*., 2008a).

Improving forage plants particularly with respect to their nutritional characteristics (e.g. improved amino acid profile, reduced rumen protein degradation, improved fibre digestibility) may also offer opportunities for reducing methane emissions from livestock.

The enzyme polyphenol oxidase is attributed with preventing protein degradation (Abberton *et al*., 2008) and enhancement of its expression offers potential to reduce loss of N from silage. Breeding plants to utilise NH_4^+ as a source of N in preference to NO_3^- reduces the formation of NO_3^- by nitrifying bacteria.

Fruit crops that are not vulnerable to damage by frost or rainfall (Whitehouse, 2009) potentially allow increased and more efficient production of crops without the use of polytunnels. This removes a significant contributor to the CO_2e emissions of some crops from the production cycle. In rice production the use of rice cultivars with low rates of exudation (Aulakh *et al*., 2001) are cited as a key measure to reduce emissions of CH_4.

The genetic modification of crops is another means currently studied with regard to a possible use in modifying crop management practices. It may include N use efficient varieties (use less mineral fertiliser N) or expression of insecticide resistance e.g. *Bacillus thurgiensis* protein (less manufactured insecticide and elimination of fuel for application). At present Bt Maize is the only GM crop authorised for cultivation in the EU (Gómez-Barbero and Rodríguez-Cerezo, 2008). The full impact of cultivating GM crops is however uncertain and their widespread adoption for use as a potential GHG mitigating tool requires caution. The growing of these crops within Europe would need a full risk assessment before approval. Although not a technique that has been fully validated the use of plants with improved nitrogen use efficiency may prove valuable in the future. During the growing period the efficiency of uptake of applied mineral fertiliser N typically ranges between 55-70% (MAFF, 2000), according to site conditions, the amount of soil N and the inherent physiology of the plant. If the plant can be rendered more competitive for soil N, even during periods when there is excess and the plant is not growing optimally, reduced N_2O emissions would be expected. The introduction of drought resistant crop varieties or those more tolerant of warmer temperatures would reduce the need for irrigation, an energy intensive operation (Dalgaard *et al*., 2001).) This might perhaps be a more plausible type of GM for use in climate mitigation, as it might be more rigorously targeted manipulation vis-a-vis climate resistance, rather than a GM involving the change in the dynamic of the biotic environment. Yield improvement is often mentioned as a benefit of GM crops, however there is currently little evidence from commercially available varieties to support this ascertion.

3.3.1.17. Cross-cutting issues: Review of calculation techniques

The indirect emissions from product manufacture (e.g. fertilisers, polyethylene) originate from detailed life-cycle analyses (LCA) and are generally highly robust. Machinery depreciation tends to be estimated but depends upon the type of machine and implement rather than location and as such these estimates are applicable across the EU. Soil N_2O emission is an area of significant variation and uncertainty. IPCC Tier 1 and national inventories calculate emission of N_2O from soils but these emissions may be overestimated under certain conditions e.g. arable mineral soils in the UK (Brown et al., 2002; Dobbie and Smith, 2003) but underestimated in others. They do not account for modifications to timing, soil type and annual rainfall. It also omits N_2O released from mineralisation of clover residues. The method used to calculate nitrous oxide (N_2O) emissions from soil due to denitrification from the application of fertiliser N used in national GHG Inventories may be based upon the IPCC (2006) Tier 1 method. It is applied to the entire Member State and derived from the total quantity of N fertiliser applied within that Member State. More detailed and more accurate calculations applicable at the regional scale may be obtained from sources such as peer reviewed publications or at the farm / parcel level from Decision Support Tools. Such calculations take account of region specific variation such as climate and dominant soil type. It is foreseen that the population of the database will require some data derived by meta-modelling with Decision Support Tools (an overview of potential tools is provided below).

3.3.1.18. Cross-cutting issues: Existing models and tools designed to assess GHG emissions and carbon sequestration

Decision support tools contain substantial data from field trials, monitoring and experimental analyses. Their use may however be time consuming and require a significant input of time. The IPCC (2006) methodology uses default values for calculating N_2O emissions in the absence of national or regional data (Tier 1 approach) but recommends incorporation of national data if available (tier 2 or 3 approach). The Tier 1 approach is criticised for the over-estimation (Dobbie and Smith, 2003) and under-estimation of soil N_2O emissions depending on soil conditions. Where relevant, meta-modelling with available Decision Support Tools may be undertaken to derive emission factors not available in published literature. Potential models include:

1. **CALM**: Carbon Accounting for Land Managers developed by the Country, Land and Business Association (www.calm.cla.org.uk) for farmers and land manager in the UK. It uses the IPCC methodology (IPCC, 2006) with some adjustments to adapt the methodology to the farm level and follows guidelines provided by the UK Department for Environment, Food and Rural Affairs (Defra) and the GHG Protocol Standard (WRI and WBCSD, 2004).
2. **CENTURY**: simulates C, N, P and S flows for plant-soil interactions in grassland and cultivated land. The primary function is to assess the impact of climate and management practices on soil organic matter.
3. **CERES-EGC**: soil-crop model that includes soil, water and temperature dynamics. Models N_2O emissions in response to fertilizer N (Bareth, 2001).
4. **CLEAN 1.0**: GHG emissions from cultivated land and livestock systems.
5. **Climate Friendly Food**: C and N (Tier 1) calculator tool for organic farmers. Includes sequestration. http://www.climatefriendlyfood.org.uk/.
6. **C-PLAN**: C and N calculator tool including sequestration. www.carbonplanner.co.uk/.
7. **Dairy Crest Direct CO_2 emissions footprint tool**: calculates energy use and CO_2 emissions from dairy farms in the south and west of England. Allows 'what if' scenarios alternative production methods. http://www.cse.org.uk/projects/view/1089
8. **DAYCENT:** models emissions of N (NO_2, NO_x and NH_3) from agricultural land.
9. **DNDC / DNDC-UK** (DeNitrification-DeComposition): (Li *et al.*, 2002). Crop – soil model that models emissions of CO_2, N_2O, CH_4, NO, N_2 and NH_3. Includes soil carbon dynamics and leaching of NO_3^-.
10. **DairyWise:** a whole system dairy farm model. It includes all aspects of dairy production (e.g. buildings, feed, livestock, grassland) (Schils *et al.*, 2007). This system is only available in Dutch and is not freely available.
11. **DIATERRE** (Planète2): A French tool for estimating energy consumption and GHG emissions at the farm level (http://www2.ademe.fr/servlet/getDoc?id=11433&m=3&cid=96). This tool is still being developed.
12. **E-CO_2**: identifies opportunities for energy and water saving on farms (CMS/Kite consulting).
13. **ERICA:** An Italian on-line software tool developed by the University of Milan on behalf of the Lombardy Region to calculate the emissions from farms involved in the IPPC Directive. It is a similar tool to NetIPPC (see below).

14. **EU-Rotate_N** (EU). Builds on the WELL-N model. Simulates N dynamics in vegetable crops applicable to Europe.
15. **FarmGHG:** models C and N flows in dairy farms (Oleson *et al*., 2006). It quantifies direct and indirect emission of N_2O and CH_4 and includes upstream emissions from manufactured imports (including feed) to the farm. Does not account for N loss from soils and C loss via respiration. Also calculates eutrophication.
16. **FarmSim:** C and N dynamics simulator for dairy farms. Includes the PASIM model, uses Tier 1 and Tier 2 methodology to calculate N_2O and CH_4 from cropland, housing, livestock and feed.
17. **FiM** (Feed into Milk): GHG calculator for forage and concentrate crops used on dairy farms (Thomas, 2004).
18. **GESTIM**: French methodological guide for estimating GHG emissions associated with agricultural activities. (http://www.inst-elevage.asso.fr/html1/spip.php?page=article_espace&id_espace=933&id_article=17281).
19. **GLEAMS**: Supersedes the CREAM model. Simulates fate of agro-chemicals, sedimentation hydrology and soil erosion.
20. **GREENERGY** (Energy optimization in greenhouses): models energy consumption in glasshouses for a variety of crops, structural modifications and modifications to management (humidity and temperature set-points).
21. **GrowHow Nmin**: calculator tool applicable to arable crops that also advises on optimal timing (in addition to residual soil N) based on crop growth stage (GrowHow Ltd).
22. **IDEA**: Indicateurs de Durabilité des Exploitations Agricoles (farm sustainability indicators - http://www.idea.portea.fr). A French diagnostic tool based on quantitative indicators that includes agricultural-ecological, a social-regional and economic scales. It is used to assess the strengths and weaknesses of production systems and to identify improvements leading to greater sustainability.
23. **LEACHM**: models leaching of N and plant N uptake. Also includes transport and fate of pesticides and P.
24. **MAGPIE**: GIS framework to model diffuse agricultural pollutants at catchment, regional and national scale.
25. **MANNER**: provides output of leaching and volatilization from field application of livestock manures (Chambers *et al*., 1999). It accounts for alteration to application method, previous storage, soil type, timing and excess winter rainfall. A tool of potential use meta-modelling the impact of different manure application strategies.
26. **MANNER-NPK**: supplementary to MANNER also predicts P, K, Mg and S supplied by manures.
27. **MANNER-PSM**: further development of MANNER that allows risk of pollution swapping (NO_3^- / N_2O / NH_3) between different management practices.
28. **MEASURES**: developed by Cranfield University, UK a Life-Cycle Analysis spreadsheet calculator that includes direct emissions from fuel consumption e.g. by machinery, indirect emissions from product

manufacture and emissions from livestock. The calculation of N_2O from soil is based largely on the IPCC (2006) Tier I method.

29. **MIDAIR**: greenhouse gas mitigation for organic and conventional dairy production. MIDAIR was an EU FP5 project that aimed to identify region and system specific, cost-effective GHG mitigation measures and strategies for organic and conventional dairy production in Europe. MIDAIR provides a description of GHG emissions from dairy production within five regions; both modelling and targeted measurements to fill gaps of knowledge are performed to describe GHG emissions at this level of resolution. Secondly, the developed models are extended to identify cost-effective mitigation measures and strategies, assisted by data from studies of various specific management options. The GHG mitigation potential for all dairy regions in Europe is quantified by up-scaling. Agronomic, environmental and socio-economic consequences of complete and partial adoption are assessed and recommendations are given to farmers, scientists and policy makers (Clemens *et al*., 2006; Schelde *et al*., 2004).
30. **MITERRA-DSS**: quantifies measures to mitigate CO_2, N_2O and CH_4. Also accounts for economic and other environmental impacts.
31. **N-ABLE:** primarily a crop growth response model to N but also simulates N leaching. Calculates NO_3^- at different depths in the soil profile in response to fertilizer N and crop management regime.
32. **NARSES:** agricultural NH_3 emissions and abatement measures (Webb and Misselbrook, 2004).
33. **N-Cycle**: nitrogen cycle model applicable to grassland. Primarily designed as a teaching tool it simulates denitrification, NO_3^- leaching and NH_3 from pasture.
34. **NEAP-N** (National Environment and Agricultural Pollution Nitrate): tool to assess NO_3^- leaching from agriculture at the national scale.
35. **NetIPPC model :** a model that was developed by CRPA in Italy (I) to calculate the emissions of NH_3 and CH_4 in the intensive livestock farms involved in the IPPC Directive (pigs and poultry farms).
36. **NNFCC Anaerobic Digestion Cost Model**: economic calculator tool to calculate the cost of anaerobic digestion (AD) facilities. http://www.nnfcc.co.uk/metadot/index.pl?id=7197;isa=DBRow;op=show;dbview_id=2539.
37. **PASIM:** pasture simulation model that calculates net balance of CO_2, N_2O and CH_4.
38. **PAS2050** BSI (2008): provides a standardised method to calculate the greenhouse gas emissions of a product.
39. **PLANET**: Decision Support Tool that advises on N fertiliser and manure best practice for a variety of crops based on field location, soil type and cropping history (incorporates RB209 recommendations).
40. **PLANETE – GES** – French developed tool
41. **PSYCHIC:** phosphorous risk assessment and DST aimed at managing P loss from agricultural land.
42. **RB209**: crop N recommendations (UK) that accounts for residual soil N (based on previous crop, annual rainfall and soil type) (MAFF, 2000). Provides figures for N content of different livestock manures dependent on previous storage, time of year and application method.
43. **ROTH-C**: soil C model. Calculates emissions (CO_2), C sequestered and net balance.

44. **SeqCure model -** It is a model available in Italy that allows the evaluation of the consequences of different crop rotations and fertilisation practices on N_2O and CO_2 emissions, and C sequestration of. It is implemented as an on-line tool, with a user-friendly interface. It is suitable for both farmers and policy makers to assess the environmental effects of different farming practices and scenarios.

45. **SIMS$_{DAIRY}$**: GHG calculator for dairy farms that incorporates a number of existing models (NGAUGE, NARSES, PSYCHIC, FiM) to calculate emissions of N_2O, CH_4, NH_3, NO_x, NO_3, and P (Schils *et al*., 2007). It calculates emissions from imported materials, soils, forage crops and livestock taking account of local climate variables and soil type. It is unique in that it is able to optimize multiple objectives.
46. **SUNDIAL:** simulates denitrification, nitrification, volatilisation and N leached in response to soil type, daily rainfall, temperature and evapotranspiration (Smith *et al*., 1996). IPCC Tier 1 or country specific emission factors may be applied to the model outputs listed to devise N_2O emissions (Warner *et al*., 2005, 2008ab). Potential to adapt to all EU Member States subject to the provision of daily rainfall, temperature and evapotranspiration. Climate data of this nature may not exist in countries within the Continental region and eastern parts of the Southern Mediterranean region. In the UK it is available from the MET Office at a cost per weather station. Reference year datasets are available for countries such as Denmark and Holland. It does not account for alteration to application method for livestock manures.
47. **WELL-N:** (Rahn *et al*., 1996). Predicts optimal N use for 24 arable and horticultural crops. Accounts for expected yield, geographical location, weather, soil texture and contribution of nitrogen from previous crop residues.
48. **YARA Nplan**: N application optimiser tool based on RB209 but includes timings for split dressings.

3.3.1.19. Cross-cutting issues: Existing databases and data inventories

There are a number of databases and data inventories that hold data related to GHG emissions and carbon sequestration. Those examined in detail for their applicability to this project include:

1. Common Agricultural Policy Regionalised Impact Modelling System (CAPRI) http://www.capri-model.org/index.htm : An EU funded tool that compares the environmental impact of different policy strategies projected into the future. Relevant environmental indicators include agricultural emission of N_2O and CH_4 (calculated using Tier II approach), NH3 and farm energy consumption.
2. European Environment Agency. Aggregated and gap filled air emission data (http://www.eea.europa.eu/data-and-maps/data/eea-aggregated-and-gap-filled-air-emission-data-3).
3. European Soil Organic Carbon database (http://eusoils.jrc.ec.europa.eu/website/octop/viewer.htm). Holds data of the organic carbon and organic matter content of European soils with associated databases of land cover, climate and topography.
4. European Environment Agency. European Union Emissions Trading Scheme (EU ETS) data from CITL (http://www.eea.europa.eu/data-and-maps/data/european-union-emissions-trading-scheme-eu-ets-data-from-citl).
5. European Environment Agency. National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism (http://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-1).

6. European Environment Agency. National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) (http://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-convention-on-long-range-transboundary-air-pollution-lrtap-convention-3).
7. European Soil Compaction Susceptibility (http://eusoils.jrc.ec.europa.eu/library/themes/compaction/Data.html). Includes a map of the natural susceptibility of agricultural soils to compaction (low, medium, high and very high).
8. IPCC emission factor database (EFDB - http://www.ipcc-nggip.iges.or.jp/EFDB/)
9. European Environment Agency. National Emission Ceilings (NEC) Directive Inventory (http://www.eea.europa.eu/data-and-maps/data/national-emission-ceilings-nec-directive-inventory-1).
10. Pan-European Soil Erosion Risk Assessment (PESERA) risk of soil erosion (Kirkby *et al*., 2003) (http://eusoils.jrc.ec.europa.eu/library/themes/erosion/) Soil erosion by water and risk in Europe, also includes estimates of tillage and wind erosion.
11. Various national emissions inventories such as those available via the UK National Atmospheric Emissions Inventory (NAEI) website (http://www.naei.org.uk/) and those held by the French Interprofessionnel Technique d'Etudes de la Pollution Atmospherique (CITEPA).
12. JRC AFOLU database (http://afoludata.jrc.ec.europa.eu/index.php/public_area/home)

3.3.1.20. Cross-cutting issues: Projected impact of climate change

Previous sections have identified the impact of climate on GHG emissions and potential mitigation strategies. Climate change and alteration of rainfall and temperature in some regions of Europe may alter the importance of mitigation strategies within particular regions.

Vegetables, fruit and sugar beet crops are vulnerable to water deficiency, even in the wetter regions of Europe such as the UK (Tzilivakis *et al*., 2005a and b). Predicted decreases in annual rainfall make strategies that optimise water efficiency more critical. Provided potential water shortages are addressed the extended growing season may permit increased growth in indeterminate crop species such as sugar beet and carrot (Wheeler *et al*., 1996; Wurr *et al*., 1998) and therefore potentially improve output per unit of input. Projected temperature increases will reduce the heating and therefore natural gas consumption associated with glasshouse vegetable production in the northern agro-climatic regions, but will increase emissions associated with cooling. Also, while heating needs may decline in a given place, it is also possible that the production systems will migrate north and such benefits will be lost.

The compaction of soil may be problematic if machinery enters the field when it is excessively wet (Soane and van Ouwerkerk, 1994) but may be unavoidable if e.g. rainfall persists during the harvest period. Agro-climatic zones that currently experience excess rainfall during such periods will, under decreased rates of rainfall, have a potentially greater number of machinery workdays (MacDonald *et al*., 1994). A reduction in the likelihood of poaching by livestock, identified as a means of agricultural GHG mitigation by Moorby *et al*. (2007) is also probable (Rounsevell *et al*., 1996). Alteration to sowing dates and the growing of longer season cereal cultivars have been recommended in regions where temperature increase is likely to reduce yields (Olesen *et al*., 2000; Tubiello *et al*., 2000; Oleson and Bindi, 2002). In potato crops earlier planting combined with cultivating earlier varieties has been recommended (Wolf, 2000). This may require machinery access earlier in the season when damage to soils (e.g. compaction) is a greater risk.

Good agricultural practices defined within the context of the Nitrates Directive and a number of authors (e.g. Chambers *et al*., 1999; Moorby *et al*., 2007) emphasise the importance of maximising and accounting for the available N within livestock manures. The rate at which N mineralisation proceeds within manures, both during their storage and after their application, may be altered under projected climate change scenarios (Sommer and Olesen, 2000; Oleson and Bindi, 2002). This affects the quantity of N available to the crop within a manure, and has implications for the N availability in existing nutrient recommendations (e.g. those given by MAFF (2000)). Recalculation may be required for individual Member States, depending on their climatic zone. This will be essential in order to maximise the available N and prevent over or under estimation of supplementary inorganic N fertiliser. It is forecast that increased temperature (Serraj *et al*., 1998) and CO_2 (Schenk *et al*., 1995) will result in a corresponding increase in the N fixed by legumes which will be of particular benefit to grassland containing clover and may eliminate the need for additional N input as mineral fertiliser or livestock manure.

Many regions are predicted to experience a decrease in annual rainfall but wetter winters and a higher probability of extreme rainfall events (Iglesias *et al*., 2006). This causes increased risk of soil erosion, loss of P and loss of embodied emissions in P fertiliser manufacture, and loss of SOC. Measures that prevent soil erosion will be increasingly more important in mitigating GHG emissions.

The impact of climate change on forage crops and enteric fermentation depends on which parameter (elevated CO_2 or temperature) the crop responds to (Oleson and Bindi, 2002). If the response is mainly to elevated concentrations of CO_2 forage crops such as cereals for silage are likely to increase in yield but decrease in digestibility and increase the CH_4 produced by enteric fermentation (Sinclair and Seligman, 1995). If the response is mainly to increased temperature it will reduce yield but increase digestibility.

The rate of SOC oxidation increases in response to warmer temperatures and decreased water availability (Smith *et al*., 2008a). Increased decomposition may be particularly pronounced in climates of mean temperature below 10 $^{\circ}$C (Smith *et al*., 2008b) and as a consequence, strategies that protect peat soils in such regions will be of greater relevance.

3.3.2. Activity 2.2. Consultation exercises

Whilst the literature and data review captured the scientific studies, past and present, relating to climate change mitigation there are also significant initiatives being undertaken or planned in the various Member States that either aim to help combat climate change directly or which offer benefits, indirectly. In order to gain information on these initiatives consultation exercises in seven Member States were undertaken by project partners.

The first stage of this work was to develop a pro-forma such that the information gathered from the different participants was all in a similar format.

The consultation exercises were carried out in two parts. Firstly a range of individuals (policy makers, industry representatives, farming/environment NGO's and farm advisors) and policy strategy documents were consulted to gain a picture of the national and regional initiatives implemented to combat climate change effects arising from agriculture. Secondly a wider range of individuals were approached to gain their views on the tools, models and services available to both policy makers and farmers for supporting climate change mitigation activities. A summary of the findings is given in Table 3.3.1.

Table 3.3.1: Key points arising from the consultation exercises

Member State	Key Points
United Kingdom	• On track to meet its 2008-2012 Kyoto targets; • An expert Committee on Climate Change has been established; • Government Department on Energy and Climate Change established which published the National Strategy for Climate and Energy; • Defra (and devolved administrations) are responsible for delivering low carbon farming; • Voluntary approach has been largely adopted (increasing uptake of best practice) but this is supported by regulation in key areas such as the nitrates directive implementation, Cross Compliance, Catchment Sensitive Farming, Environmental Stewardship Schemes; • Support initiatives include Primary Production Assurance Schemes, websites, GHG calculators, specialist advice (e.g. National Non-Food Crops Centre, Biomass Energy centre).
France	• On track to meet its 2008-2012 Kyoto targets; • Policy strategy document published 'Objectives land 2010: towards a new French model for Agriculture' which aims to deliver a more sustainable farming system including aim of reducing energy dependence; • Key policy instruments include NVZ Regulations, 2010 carbon tax on fossil fuels, environmental labelling on consumption products, National Air Quality Plan, financial incentives for farms to reduce consumption of fossil fuels and energy.
Germany	• Largest emitter of GHGs in EU but large reductions already achieved- expected to meet its 2008-2012 Kyoto targets; • Financial incentives available for increasing energy efficiency and using renewable energies; • Introduced a Sustainability Strategy for agriculture sector to drive forward climate change adaptation and mitigation plans; • Key policy instruments include regulations related to water use and protection, use of synthetic fertilisers, NVZ Regulations, soil protection, recycling and waste regulations, Cross Compliance and promotion of good practice.
Italy	• No national adaptation strategy; • National and regional investment to improve energy efficiency and promote good practice; • Key policy instruments include NVZ Regulations, Water framework Directive, Cross Compliance, Ministerial decrees related to livestock manures, renewable energies and IPPC.
Poland	• Polish Climatic Policy in place to improve agricultural sustainability particularly with respect to improving energy efficiency, enlarging woodland/forests and soil resources and waste management; • Action directed towards improving the national organisational, institutional and financial status of Poland in order to fulfil Kyoto obligations; • Regional programmes in place to improve livestock feeding techniques, diets, housing and manure management; • Key policy instruments include NVZ and fertiliser regulations, regional water management, II national Environmental Policy and the Strategy of Renewable Energy Development, promotion of organic farming and good practice.

Member State	Key Points
Slovenia	• At risk of not meeting 2010 Kyoto targets but various programmes in place to tackle this including the Agriculture and Environment Programme; • Investments to improve forestry and woodland management to increase carbon sequestration; • Polices in place to deliver a more sustainable agricultural sector- focus is on livestock sector, infrastructure and machinery improvements and, soil and water management; • Key policy instruments include carbon tax, increasing use of renewable energies, promotion of organic farming, National Energy Program, Slovenia's Development Strategy, rural development policies, Water Framework Direct, NVZ Regulations.
Hungary	• Several ongoing investment strategies in place to modernise and improve infra structure and, energy production and efficiency; • Priorities are Environmentally Sensitive Areas, areas with large water bodies, soil management and crop production strategies; • Key policy instruments include National Agri-Environment Programme, National Environment Programme, Special Accession Programme for Agriculture and Rural Development, organic farming, NVZ Regulations and National Drought Strategy.

Key points arising include:

- Generally, with respect to the agricultural sector most Member States involved in the consultation exercise have adopted a voluntary approach to reducing GHG emissions and are encouraging general good practice and the optimal use of fertilisers;
- Energy efficiency policies and initiatives widely in place;
- The less affluent Member States are focusing more on modernising and improving infrastructure and industry rather than more specific actions to reduce climate change.

3.3.3. Activity 2.3. Case Studies

A series of case studies have been undertaken in each of seven Member States to collate information from actual farms to support and supplement the findings of the literature review and the consultation exercises. Farms were selected on the basis that they have some climate change mitigation in place. The objective was to gather information on the practices that have been adopted for both reducing greenhouse gas emissions and increasing carbon sequestration. The case studies also aimed to gather data relating to the economic implications of mitigating climate change and evidence of any additional environmental benefits or burdens.

The first stage of this work was to develop a pro-forma and guidance document which was distributed to all the project partners. The purpose of this pro-forma was to help ensure that the information gathered in the case studies in each Member State was collated in a consistent format in order to aid the integration of information into the database and 'tentative' model. The guidance notes also provided the researchers undertaking the case studies with information on the scope of the activities they should examine with examples of what should be included.

The results of the case studies have been used in a number of ways:

1) The data collated has been used to help populate the database underpinning the 'tentative' model;
2) Each case study was converted to a Case Study Summary Sheet that has been disseminated via the IMPACCT website.
3) The information gathered has been assessed to identify trends, synergies and disparities between the various Member States and the current activities and approaches being undertaken to mitigate climate change. The findings are summarised below.

Table 3.3.2 below summarises the 23 Phase 1 case studies that were undertaken in seven Member States.

Table 3.3.2: Overview of the Phase 1 case Studies

	Member State	Farm identifier	Key activities
1	Scotland	Arbigland Estate [Arable & Beef]	• Conservation & land management • Precision & Integrated farming • Resource management (optimisation of inputs organic manures, water recovery, recycling)
2	Scotland	The Ryes [Beef]	• On-farm biogas plant • Integrated farming techniques • Energy efficiency (building lighting & insulation, dairy equipment) • Resource management (optimisation of inputs organic manures, water recovery, recycling) • Conservation & land management
3	Scotland	Barrasgate Farm [Arable, Beef & Sheep, Energy crops]	• SR willow coppice • Conservation & land management • Energy efficiency (building lighting & insulation) • Resource management (optimisation of inputs organic manures, water recovery, recycling)
4	France	Champ Farm [Arable]	• Energy efficiency (optimisation of machinery use) • Resource management (optimisation of inputs organic manures, water recovery, recycling) • Conservation & land management • Integrated farming techniques
5	France	Le fouesnard [Dairy & Field Cropping]	• Energy efficiency in dairy • Conservation & land management • Integrated farming techniques • Resource management (optimisation of inputs organic manures, water recovery, recycling) • Manipulation of livestock diets
6	France	Ferme de Grignon Experimental farm [Field cropping, Dairy & Sheep]	• Energy efficiency in dairy and other farm buildings • On-farm biogas plant • Staff training • Resource management (optimisation of inputs organic manures, water recovery, recycling) • Conservation & land management • Integrated farming techniques
7	Poland	Stefaniank Farm [Cereals, Potatoes & Pigs]	• Energy efficiency in piggery • Improved resource management • Some precision farming techniques • Conservation & land management

	Member State	Farm identifier	Key activities
8	Poland	Siechnice Hort. Production [Glasshouse crops]	• Energy efficiency in glasshouse • Drip irrigation also delivering nutrients • Biological pest control • Hydroponics
9	Poland	Kudesz Farm [Goats, Dairy]	• Energy efficiency in buildings • Re-use of whey in livestock feed • Water efficiency
10	Poland	Długosz Farm [Arable and sheep]	• Energy efficiency • Soil management, crop nutrition and fertiliser efficiency
11	Italy	Cotti Farm [Dairy, Arable & Tomatoes]	• Soil & land management • Soil nutrient management plans • Energy efficiency in farm buildings • Resource management (organic manure use, water recovery/recycling, recycling) • Plans to install a photovoltaic plant for farm energy use
12	Italy	Sartori & Bianchi Farm [Pigs, Feed & Tomatoes]	• On-farm biogas plant • Soil nutrient management plans • Upgrade of slurry management system • Resource management (organic manure use, water recovery/recycling, recycling) • Manipulation of pig diets
13	Slovenia	Žgajnar Organic Farm [Dairy, Sheep, Goats, &Arable]	• Energy efficiency activities (livestock buildings & machinery). • Soil nutrient management plans • Waste management (recycling & reuse) • No synthetic nutrients or pesticides
14	Slovenia	Zamet d.o.o. [Cattle, Agricultural services]	• Soil nutrient management plans • Waste management (recycling & reuse) • Energy efficiency activities
15	Slovenia	ZIPO Lenart, d.o.o. [Cattle and cattle feed]	• Energy efficiency activities (livestock buildings & machinery). • Soil nutrient management plans • Waste management (recycling & reuse)
16	Hungary	Szekszius Farm [Horticulture, Cereals]	• Water efficiency • Optimisation of crop nutrition • Experimental field
17	Hungary	Gyuricza Farm, Gödöllő [Arable, Oilseeds]	• Energy efficiency • Optimisation of crop nutrition • Experimental field
18	Hungary	István Balla Farm, Karcsa [Arable and oilseeds]	• Energy efficiency • Optimisation of crop nutrition
19	Hungary	Lovasbereny Agricultural Cooperative, [Mixed]	• Energy efficiency • Waste management • Soil and nutrient management

	Member State	Farm identifier	Key activities
20	Hungary	Poti Farm, Gödöllő [Livestock]	• Livestock diet manipulation • Manure and slurry storage
23	Hungary	Agra-Beta Farm, Birkamajor [Cereals and oilseeds]	• Energy cropping • Weather stations to improve weather predictions and climate data
21	Germany	Agrargenossenschaft [Arable, Dairy, Horticulture]	• Anaerobic digester • Solar panels feeding national grid • Energy efficiency activities (livestock buildings & machinery). • Farm water well • Conservation tillage and optimisation of field operations
22	Germany	Milchhof Blumenthal GmbH / Ökologischer Landbau Hammer GmbH, [Mixed]	• Biogas plant and Solar panels • Energy efficiency activities (livestock buildings & machinery). • Conservation tillage and optimisation of field operations, Bird conservation area • Water conservation • Wind erosion prevention programme

Overview of the findings:

- Activities related to basic energy efficiency such as installing insulation and improving equipment efficiency, especially those used for field operations such as tractors, is wide spread across all the case study Member States. However, the main motivation for this appears to be economic - to help counteract the rising costs on energy and fuel and not, at least in the first instance, for climate change mitigation.
- General good practice and the optimal use of fertilisers are also widely in place across the case study Member States. However, like energy efficiency activities, this is also primarily motivated by the need to control rising costs and, as many of the case study farms are within Nitrate Vulnerable Zones, there is a regulatory requirement to adhere to prescribed nutrient management practices.
- A striking observation of the information arising from the case studies is that the affluence of the Member State is reflected in the type and extent of the climate change mitigation options currently being undertaken. For example, the mitigation activities identified from the case studies carried out in Poland, Hungary and Slovenia were quite basic and needing little capital investment, relying predominately on general good agricultural practice (e.g. efficiency use of inputs, energy and water and waste management). Whereas in Member States such as the United Kingdom, France, Germany and Italy there are many cases where quite large financial investments are being made in new technologies (e.g. biogas plants, photovoltaic panels) as well as efforts to improve general practices.
- Two examples of where precision farming techniques are being used were identified and whilst initial capital investments were required benefits both in terms of cost savings and greenhouse gases being emitted are anticipated.
- Fuel and energy efficiency, fertiliser optimisation and soil management were the main climate change mitigation activities undertaken on the arable and cropping farms taking part in the case studies.

Whereas on the livestock farms manure management, manipulation of livestock diets and energy efficiency in livestock housing were the main activities.

3.3.4. Activity 2.4. Data recording and reporting

The priority aim of the 'tentative' model is to identify climate change mitigation strategies and not necessarily, at least in the first instance, to calculate a highly accurate and full Carbon balance. The literature and data search identified many potential mitigation options but frequently the data is not as complete or as accurate as would be preferred. There are many data gaps and estimations rather than firm and reliable figures. It is anticipated that situation may improve in the future in response to improved data. However, these types of data have still been included in the model databases albeit the assigned data quality scores (see Section 3.5.4 below) are low due to estimation or limited data being available. This has been clearly identified. The following Sections summarise how data for inclusion within the 'tentative' model has been generated and then used.

3.3.4.1. Livestock: Enteric fermentation and nutrient use efficiency

Requests were made during the consultation that mitigation strategies and their impact be displayed per head or per livestock unit. Dairy cows have three milk yield modifiers (low, moderate and high) for spring or autumn calving based on those described in the ISO 205 calculator tool (Williams *et al*., 2009). For each yield the voluntary feed dry matter intake identified by ISO 205 defines the quantity of total of feed dry matter consumed. Feed properties of pertinence to GHGs (crude protein content, volatile solids (VS) and starch) per kg dry matter of each feed type have been derived from the Feed into Milk (FiM) database (Thomas, 2004). The FiM database contains approximately 150 feed types offering the potential to be used in any combination. Accounting for all feed types would generate huge numbers of permutations and render the tool potentially unusable because of the complexity of choices available to the user. Diets are composed of combinations of 10 individual feeds, selected mainly in response to those specified as used by farms within the consultation, with an additional concentrate mixture consisting of 60% wheatfeed, 20% barley and 20% rapeseed defined as typical by Williams *et al*. (2006). Exact formulations of concentrates are variable and not readily available. They are summarised in Table 3.3.3.

Twelve diets (modifiers) that satisfy the voluntary feed DM intake for each milk yield (Williams *et al*., 2009) with different combination of the feeds listed in Table 3.3.3 based on the proportions used in the ISO 205 tool have been formulated. They represent different quantities of N, starch and proportions of concentrate within the diet.

The N excreted may be increased by excessive intake of N by the animal which is not utilised for growth or milk production. The N content of feed per kg DM has been calculated using the Kjeldahl N content of protein (0.16 kg N/ kg protein) and the crude protein values in Table 3.3.3, then used to calculate the total N intake for each diet. Nitrogen is removed in milk and by animal growth (derived from the ISO 205 tool; an overview is given in section 2.10.3.1 of Williams *et al*., 2006) and the remainder excreted (IPCC, 2006; Williams *et al*., 2009).

Table 3.3.3: Properties of feed types used in the example diets (from the Feed into Milk database)

Feed type	Crude protein N (kg/kgDM)	ME (MJ kg DM)	starch (g/kgDM)	VS (kg/kgDM)
grazing	0.0248	11.2	0	0.359
clover (red) aerial part (fresh)	0.0392	10.5	0	0.254
kale	0.0256	12.0	0	0.343
lucerne (fresh)	0.0282	9.8	0	0.252
fodder beet	0.0096	12.0	0	0.358
grass hay (average)	0.0182	8.6	0	0.363
grass silage (average)	0.0338	10.8	0	0.346
maize silage	0.0144	11.0	250	0.367
lucerne silage	0.0304	8.5	0	0.246
wheat whole crop fermented	0.0152	10.5	200	0.364
dairy concentrates[1]	0.0357	11.8	267.8	0.209

[1]60% wheatfeed; 20% barley; 20% rapeseed meal

A greater proportion of feed concentrate compared with roughage results in a decrease in CH_4 per MJ of dietary energy, per kg of feed intake and per kg of product (Beauchemin *et al*., 2008; Johnson and Johnson, 1995; Lovett *et al*., 2006; Mills *et al*., 2003; Smith *et al*., 2008; Yan *et al*., 2000). The ISO 205 tool calculates enteric methane values based on the proportion of concentrates and forage and this method has at present been used to meta-model the enteric methane generated by each diet. It does not however differentiate the methane generated by consumption of feeds with different starch contents, identified in preliminary findings by Beauchemin *et al*. (2008) as a potential means to reduce enteric CH_4. The DST $SIMS_{DAIRY}$ and DAIRYWISE have the capability but are not publically available tools and require interpretation of results by a member of the development team. There is potential to generate data for a small number of feed scenarios by kind cooperation of members of the respective development teams but this is subject to constraints on their time. Other enteric CH_4 mitigation strategies include dietary additives reviewed by Smith *et al*. (2008) who estimates the mean reduction from their use. The modifier 'dietary additives' reduces the CH_4 per LU for each example diet by the reduction estimated by Smith *et al*. (2008).

Volatile solids per kg of DM for each feed type are provided by the FiM database and have been used to calculate the total VS for each diet based on its constituent feeds. They are used in the calculation of CH_4 emitted from manures (following section).

3.3.4.2. Livestock: Housing, manure and slurry management

Emission of N_2O and CH_4 occurs during storage of manures. Factors of relevance to N_2O emission during manure storage per head of cattle (and modifiers within the 'tentative' model) include the quantity of N excreted (kg N per head, modified by diets 1 to 12) and storage method i.e. solid, slurry, uncovered anaerobic lagoon (Chadwick, 2005; IPCC, 2006 Tables 10.21, 10.22 & 10.23; Williams *et al*., 2009). The IPCC (2006) provides default N_2O emission factors for direct and indirect N_2O emissions for specific livestock manures (modifier) and particular methods of storage (modifier). These have been applied to the quantity of manure N excreted for each diet (modifier) in relation to the total N intake associated with that diet minus that retained by the animal (e.g. for growth). A further variable is the proportion of the N excreted that will be deposited directly onto grassland which is dependent on the period of housing. The model allows the user to designate the proportion of time that animals are housed for. Emission of N_2O from N deposition is potentially greater at higher stocking levels because of greater probability of urine patches overlapping, particularly close to feeding troughs (ADAS, 2007a; Shorten and Pleasants, 2007). The IPCC (2006) method provides further default N_2O emission factors for deposition on grass per kg N excreted. Where the modifier 'move feeding troughs' (frequent re-siting of troughs to avoid trampling and compaction of soil by livestock) is not selected the N_2O emission factor has been increased but this at present an estimate and highlighted as a data gap. Other livestock categories include cattle, sheep and pigs. Production scenarios (e.g. feed intake) are based on those described by Williams et al. (2009).

Methane produced during manure storage is influenced by the total VS content of the manure, a result of the type of feed and quantity of that feed within the diet (modified by diets 1 to 12). Other factors (and modifiers) include the method of storage (Chadwick, 2005; IPCC, 2006; Williams *et al*., 2009) and temperature (IPCC, 2006). Different modifier temperatures may refer either to ambient storage conditions or selection of a cooler temperature to artificially cool e.g. slurry to reduce CH_4 emission. The IPCC (2006) formula (equation 10.23 and Table 10.17) has been used to calculate kg CH_4 per kg of VS for a given storage method and temperature and then combined with the total kg VS calculated for each diet as a product of its constituent feeds (from the FiM database) and their respective weight in DM. For each type of livestock housing a baseline energy consumption value is defined per head or per livestock unit (LU). It is then reduced by implementation of a mitigation strategy (modifier). For dairy enterprises baseline energy (delivered electricity) consumption is calculated per head for three modifiers: small (up to 88 head), medium (88 – 140 head) and large (over 140 head) enterprises (CALU, 2007). The CO_2 emissions are adjusted depending on the source of electricity. The baseline energy consumption per head is split between vacuum pump operation, space heating, heating hot water for cleaning, lighting, udder washing and milk cooling (CALU, 2007). Examples of strategies that reduce the baseline energy consumption (modifiers) include insulation, low energy bulbs, vacuum pump with variable speed controls (for both milking and washing), heat recovery installation, air source heat pumps, using rainwater instead of mains for washdown and using a coldwash system.

Baseline energy consumption in pig units are split per head by size of unit (modifiers): small (up to 1200 head), medium (1200 – 2100 head) and large (over 2100 head). Example mitigation strategies (modifiers) that reduce the baseline energy consumption include reduced air leakage, under-floor heating, dimmer switches on lamps, optimal fan number and maintenance.

Poultry are categorised by modifiers that specify type and size and include broilers (small unit up to 200000 birds and large unit over 200000 birds) and layers (small unit up to 75000 birds and large unit over 75000 birds). The baseline energy consumption and savings reduction associated with each mitigation strategy (modifier) are calculated per head. Modifiers include insulation (and keeping it dry), optimal passive ventilation, regular cleaning of lights and optimal lighting. The cooling of roofs using harvested rainwater ('grey water') as opposed to mains eliminates emissions from mains water treatment.

Note: The application of slurries and manures is covered in the next section (crop nutrition) because they are regarded as a fertiliser resource (rather than a waste) within the 'tentative' model.

3.3.4.3. Cropping: Crop nutrition

Emission of N_2O in soils are mainly due to microbial nitrification (oxidation of ammonium (NH_4^+) from decomposing plant biomass to nitrate (NO_3^-) under aerobic conditions) and denitrification of NO_3^- to mainly dinitrogen (N_2) under anaerobic conditions (Machefert *et al*., 2002). A greater proportion of the N is converted to N_2O when denitrified (DeVries *et al*., 2003). Specific amounts of N_2O released from soils are difficult to predict, subject to uncertainty and highly variable both temporally and spatially i.e. dependent on the time of year and site-specific variation (Machefert *et al*., 2002). Variation in annual precipitation patterns and soil type (due to different agro-climatic regions within Europe) impact on N_2O-N emissions from agricultural land.

Inorganic N application. Several mitigation strategies aim to optimise the application of inorganic N, or substitute it with alternatives, to reduce its overall use. Decision support tools (e.g. SUNDIAL) allow the soil N loss from nitrification, denitrification, nitrate leaching and volatilisation to be simulated for individual crop types, soil types, daily rainfall, N application rates and timings. There are many possible permutations and although potentially highly accurate (data quality score of 5) considerable time and effort to simulate every possibility would be required in developing the 'tentative' model. An alternative approach taken has been to develop modifiers for soil type and annual rainfall per kg N applied rather than calculate the total emissions for specific application rates. The IPCC (2006) methodology has been modified to account for the impact of soil type and annual rainfall on denitrification, nitrate leaching and the volatilisation of N. Simulations with the N balance model SUNDIAL (Smith *et al*., 1996) have generated nitrification, denitrification, N leaching and volatilisation values for a crop in receipt of recommended N that accounts for residual soil N (MAFF, 2000) on three different soil types (sand, loam and clay) for three different annual rainfall categories (<600 mm, 600-700 mm, >700 mm) (modifiers). The output has been used to adapt the direct soil N_2O emission factor, the Frac(LEACH) and Frac(GASF) values of the IPCC (2006) formula and generate N_2O emissions per kg N applied for each modifier. De Vries *et al*. (2003) calculate the fraction of N released during nitrification and denitrification that forms N_2O, as 0.0125 and 0.035 respectively, on mineral soils. These fractions have been used to quantify the emission of N_2O from the N that is nitrifified and denitrified as generated by the SUNDIAL simulations. On peat soils De Vries *et al*. (2003) calculate that greater quantities of N_2O are released, a mean fraction of 0.02 and 0.06 of the N released from nitrification and denitrification respectively, that forms N_2O. Further simulations have been undertaken to ascertain direct soil N_2O emissions, the Frac(LEACH) and Frac(GASF) where over application of N (e.g. due to failure to account for N in manures) has occurred. These values are used to predict soil N_2O emissions for the following mitigation strategies (modifiers).

Testing soil for residual N status / accounting for residual soil N. The consultation revealed that several farms tested the soil to determine its N content to calculate fertiliser N requirements more accurately. The soil N status is highly spatially variable and determined by previous cropping history, soil type and rainfall. It will be farm specific. Residual soil N determination has been based on the soil nitrogen supply (SNS) method in RB209 (MAFF, 2000). The modifiers SNS known or SNS unknown determine if an assessment of soil N status has been undertaken. If the 'SNS known' modifier is selected then the user will have accounted for the residual soil N which will be reflected in the total N they enter. The soil N_2O emission per kg N applied is calculated with the direct soil N_2O, Frac(LEACH) and Frac(GASF) adjusted for recommended N accounting for SNS. Where 'unknown' is selected a potential 'worst case' over application scenario is assumed. The 'worst case' excess N refers to the difference between recommended N for the highest SNS for a given soil type and recommendations for the lowest (the greatest potential excess N applied). Further simulations in SUNDIAL define the direct soil N_2O, Frac(LEACH) and Frac(GASF) for a winter wheat crop in receipt of this excess N and adapt the soil N_2O emissions per kg N applied accordingly.

Precision application. Precision application accounts for within field variation in soil type and inorganic N requirement. This technique depends on the accurate determination of spatial variation in SNS on farm and is therefore variable and field specific. It improves the accuracy of N application however this is difficult to quantify exactly. The direct soil N_2O, Frac(LEACH) and Frac(GASF)for winter wheat that accounts for SNS simulated in SUNDIAL has been reduced by a further 10%. It is an estimate and has been assigned a low quality data score.

Balance fertilization / Organic N application and optimal N use in manures. Maximising the efficiency of manure N applications is considered a key agricultural GHG mitigation strategy (Moorby *et al.*, 2007) as it maximises the manufactured inorganic fertiliser N substituted. Sub-optimal use of the available N within manures results in an additional requirement for inorganic N and therefore additional and unnecessary emission of N_2O from soil. The mitigation strategy within IMPACCT is to maximise the available N within the manure (maximise amount of inorganic N fertiliser substituted) and minimise environmental loss (leaching and volatilisation of NH_3). Modifiers calculate the additional emission of N2O from sub-optimal application relative to the optimal 'best case' scenario. The available N in manures is dependent on the manure type (e.g. cattle FYM fresh, dairy slurry, pig slurry, sludges), the timing of application (autumn, winter, spring or summer), method (surface, incorporation time (6 hours, less than 6 hours), deep injection) and soil type (sand or medium / heavy) (MAFF, 2000). These variables have been used as modifiers. For each manure type the available N (kg per t of m^3 applied) for the 'best case' scenario has been set as the baseline. For each manure type the difference in available N when applied optimally and that available when applied sub-optimally for each permutation of modifier (timing, method) has been calculated. The reduction in available N (kg) for each sub-optimal permutation generates soil N_2O from the extra inorganic N required. The greater the available N the smaller is the additional need for inorganic N fertiliser. In addition, the N within the manure not utilised by the crop is increased when application is sub-optimal, and this increases the risk of N leaching (and its associated indirect N_2O emissions). The anaerobic treatment of slurries has been found to increase the available N with potential to substitute further inorganic N although data is at present limited. The N available from anaerobic treatment of dairy, beef and pig slurries (Morgan and Pain, 2008) has been increased accordingly.

The second impact on the emission of N_2O from soil, the effect of modifiers on leaching and volatilisation of NH_3 has been calculated using a combination of the IPCC (2006) method and the Decision Support Tool (DST) MANNER (Chambers *et al.*, 1999). The default proportion of the N input to the soil that is leached (Frac(LEACH)) and volatilised (Frac(GASF)) (IPCC, 2006) have been substituted with those calculated by MANNER on sand, loam or clay soil and for the stated modifier application methods.

Adjust inorganic N to account for N in manures. Failure to account for N in manures is cited as a significant contributor to excessive application of N. In the 'tentative' model it is therefore accounted for by the modifier 'adjust inorganic N to account for manure N'. Where non-adjustment is selected a 'worse case' excess N application rate equivalent to the maximum available N (optimal application) for a given manure and soil type is assumed. Additional emission of soil N_2O is calculated per kg of excess inorganic N applied per t or m^3 of manure or slurry applied. Failure to account for the nutrients in inorganic manures also incurs additional equivalent emissions from the manufacture of inorganic N, P and K applied unnecessarily.

Weather forecasts. The benefit of using weather forecasts to predict and avoid application of inorganic N before heavy rainfall (Goulding *et al*., 2006) is at present uncertain (Moorby *et al*., 2007). It is subject to variability in rainfall patterns which will vary both between years and location. It has been included as a modifier with a low data quality score, at present the Frac(LEACH) and the direct N_2O emissions have been reduced by 5%.

Nitrification inhibitors and slow release (coated) fertilisers. Available data lists several products applied to specific forms of N, for example nitrapyin, calcium carbide, polyolefin coated urea (POCU) applied to urea; 3, 4-dimethylpyrazole phosphate (DMPP) applied to ammonium sulphate nitrate; dicyianimide applied to urea, ammonium sulphate and liquid manure (Smith *et al*., 2008). The period of data collection varies between 56 days and 3 years (most studies were conducted for in the region of 100 days). Nitrous oxide emission reduction for the duration of the trials ranged between 9% (neem coating applied to urea in wheat) and 89% (dicyianimide applied to urea in spring barley). At present one modifier is specified for selection of a nitrification inhibitor (yes or no), it does not distinguish between products. The mean value of the most widely tested products with data gathered over the course of one growing season or several months has been used. The nitrification inhibitor dicyianimide applied to urea in cereals is the most widely tested and the mean 65% reduction in N_2O emissions has been applied with a data quality score of 2.

N fixation. Fixing N by e.g. clover mixtures is a potential mitigation strategy in grassland (King *et al*., 2004). Once established it offers potential to substitute inorganic N although the potential is dependent on the species and purity (Cuttle *et al*., 2003). Nitrogen fixation also results in the emission of N_2O from soil (IPCC, 2006).

Avoid application of manure and inorganic N simultaneously. Simultaneous (same day) application of organic and inorganic N (while accounting for the organic N applied and reducing the inorganic N accordingly) has been cited to risk increased denitrification. The modifier 'apply manure and inorganic N simultaneously' increases the direct N_2O emission factor by an estimated 5% (a low data quality score is given due to it being an estimate).

3.3.4.4. Cropping: Water and irrigation

'Grey water' (non mains treated or desalinated) for pesticide application or irrigation eliminates energy (electricity) and CO_2 emissions during its treatment. The modifier 'use mains water' or 'desalinated water' adds CO_2 emissions from the treatment process per m^3 used. The application of the water is also an energy intensive process and estimated as 52 MJ/mm/ha by Dalgaard *et al*. (2001). Modifiers distinguish the application method as rain-gun or trickle irrigation. Trickle irrigation delivers water at a lower pressure which consumes smaller quantities of energy, uses smaller volumes of water because evaporation is reduced and delivery is direct to the crop roots (Sakellariou-Makrantonaki *et al*. 2007). Soil moisture sensors offer potential to reduce water consumption further. Trickle irrigation delivers water at a lower pressure which consumes smaller quantities of energy. Methods (modifiers) to reduce energy consumption further include pump efficiency and use of optimal hose length (CALU, 2007) for which failure to select as a modifier increases the baseline energy consumption data per m^3 used.

3.3.4.5. Cropping: Machinery use and field operations

Energy consumption by mechanical operations has been derived from several sources. Greenhouse gas mitigation strategies seek to use alternative methods that reduce fuel consumption but achieve similar objectives. Modifiers grouped by comparable field operations (for example subsoil whole field, subsoil tramlines only; ploughing at different depths) and specify variation in tractor power (Hunt, 1995). Additional modifiers applied to each operation refer to general maintenance of machinery. For example optimal tyre pressures reduce fuel consumption by up to 15% (CALU, 2007), the referenced fuel consumption figures in the database are increased by 15% where the modifier 'check optimal tyre pressure' is not selected. Other example modifiers designed to improve fuel efficiency include a high power/weight ratio, avoidance of overpowered tractors, appropriate tyres to reduce rolling resistance, maximising traction efficiency and frequent servicing.

The impact of soil compaction on soil N_2O emissions is stated as unknown by Moorby *et al*. (2007) and is therefore at present estimated by adjustment the direct N_2O emission factor. Soil compaction may result from poaching by livestock but will be applicable to a small proportion of the total grazing area (concentrated around feeding troughs). Where zero tillage is implemented, King *et al*. (2004) calculate an additional 0.67 t CO_2e / ha from increased emission of N_2O, because of soil compaction. The 'tentative' model increases soil N_2O in grassland by an equivalent 0.67 t CO_2e / ha for an assumed compacted area of 0.1 ha within the vicinity of each trough. This additional N_2O relative to non-poached soil is then added where modifier options to avoid poaching are not selected. It is an estimate and has therefore been assigned a quality score of 2. A similar protocol has been adopted for compaction caused by tractor wheelings (entering the field when wet). The area occupied by wheelings in cultivated land is crop dependent (i.e. tramlines or row crops). Tramlines have been estimated to occupy 0.1 ha in which soil N_2O has been increased by an equivalent 0.67 t CO_2e / ha where the modifier to avoid soil compaction (not enter the field when wet) has not been selected. It is an estimate and assigned a low data quality score.

3.3.4.6. Cropping: Post harvest operations

Typical energy consumption during grain drying, potato and fruit storage are provided several authors (e.g. CALU, 2007; Mila-i-Canals *et al*., 2007; Williams *et al*., 2009). Data has been collated and used as baseline (pre-modifier) values. Emissions from grain drying are calculated per tonne of grain and specific to grain type and desired end moisture content. Example mitigation strategies include management of harvest to reduce grain moisture content pre harvest, optimal duct size, driers that use air recirculation, drier type and control of store humidity. Each modifier adjusts the baseline energy consumption value by its energy saving potential. Potato storage may be energy intensive because of chilling, particularly during warmer months (Williams *et al*., 2009). Energy reduction strategies (modifiers) include general good maintenance (e.g. sealing of doors to minimise internal / external air flow) and modification to equipment (e.g. use of low pressure fans). Each modifier adjusts the baseline energy use value (per t / year) by the decrease in energy use if selected. Mitigation strategies for the drying of bulb crops e.g. onions and the long and short-term storage of fruit are included and use the same method.

3.3.4.7. Cropping: Covered and container grown crops

Crops covered with polytunnels use significant quantities of plastics. Polytunnel covers use low density polyethylene (LDPE) which requires 78 MJ/kg and emits 0.0019 t CO_2e/kg (mean for European polyethylene production) during its manufacture (Bousted, 2003). Further CO_2 is released upon disposal (e.g. biodegradation in landfill (Eggels et al., 2001)). The polytunnel covers may be reused for up to three or four years after which light transmission through the LDPE is insufficient. The total LDPE (kg/ha) and the associated CO_2 emissions to cover a crop with a polytunnel have been calculated. The mean CO_2 emissions per year of use are calculated for between one and four years of usage (modifiers). Emissions per year of use are reduced for each additional year of useful life.

Growbags containing substrate may be used for high value crops such as strawberries. Modifiers include peat or coir substrate. Peat substrate used for horticulture is estimated to cause mean losses of 49.9 kg C/m^3 (Choudrie *et al*., 2008) accounting for 'on-site' emissions (the peatland due to extraction) and 'off-site' emissions (due to the extracted peat in each growbag). Calculations have been made for a 1 m length bag containing 5 litres (0.005 m^3) of dry peat and equivalent to 31 m^3/ha crop (Warner *et al*., 2010). Calculations for a potential alternative, coir (coconut fibre), have been made taking into account processing and transport. Emissions associated with the additional N required have, at present, been estimated per kg of N applied to the crop based on data for strawberry crops (Warner *et al*., 2010).

3.3.4.8. Cropping: Glasshouses

Meta-modelling the impact on energy consumption (and related CO_2 emissions) for glasshouse crop production (tomatoes) in north east and north-west Europe (modifiers) has been performed with the GREENERGY software (Körner *et al*., 2007). The geographic variation accounts for site specific variation in solar radiation entering the structure, the external temperature (temperature gradient between inside and outside), wind speed and atmospheric CO_2. The energy consumption is further impacted by the exposed surface area : volume ratio which is greater in smaller relative to larger units. Additional modifiers include size of glasshouse: small (up to 0.8 ha), medium (0.8 – 1.6 ha) and large (over 1.6 ha) units. The GREENERGY model has then been used to generate energy consumption data for the following example modifiers: energy consumption by reduction of set-point temperature by 1^{o}C, reduction of humidity set-points to 90%; the use of thermal screens on the side only, on the roof only and on both the side and roof; reducing the daylight threshold for when lighting is used to below 250 Wm^{-2}. The model also calculates the impact on crop yield which has been used to quantify the economic implications. The impact of using Combined Heat and Power (CHP) has been calculated by the ISO 205 model (Williams *et al*., 2009).

3.3.4.9. Cropping: Cover (or catch) crops

Cover crops potentially decrease the N leached and associated indirect N_2O emissions. There may however be additional N_2O emissions from the nitrification of the cover crop residues. A highly site specific variable the reduction in N loss due to leaching depends on the soil type, SNS index (previous cropping regime) and winter rainfall. Silgram & Harrison (1998) quote a figure of between 25 and 50 kg N/ha in northern Europe although this figure will be subject to variation for the reasons listed. The modifier 'use cover crop' at present estimates the reduction in the fraction leached per kg N applied for the three soils and annual rainfall modifiers and has been assigned a low data quality score. The additional N_2O emission from residue decomposition has been calculated from SUNDIAL simulations.

3.3.4.10. Fuels and products

Emissions from fuels consumed are listed per unit (e.g. t, litre, m^3) of fuel by type. The CO_2 emissions from electricity generation are modified depending on the mix of fossil fuels and renewables. Modifiers have been developed to include the percent renewables within the tariff. Modifiers identified for on farm energy generation include wind turbine, solar, heat pump and wood chip (electricity generation). The CO_2e per kWh generated by the renewable source (if applicable) has been incorporated into the database.

Fertilisers, pesticides, seed, machinery, polyethylene, steel are listed in many publications as kg CO_2e per kg product. Inorganic fertilisers have been converted to CO_2e per kg of nutrient. Pesticides, because of the large number of products and classes of active ingredient, and their relatively minor contribution to on farm GHG emissions have been grouped by herbicide, fungicide or insecticide (Green, 1987). The manufacture of machinery because of depreciation is calculated on a 'per ha of use' basis. Substrate used in bags (e.g. peat or coir) have been calculated per kg and per bag of specified volume taking account of upstream emissions such as extraction, peatland drainage and transport.

3.3.4.11. Carbon: Soil Organic Carbon

The mean baseline soil organic carbon (SOC) values of four soil types (modifiers) (organic, organomineral, mineral and 'other') to depths of 30 cm are provided by Dyson *et al*. (2009) for the following land uses (modifiers): cropland, grassland and forestland. The SOC is lowest in cropland. The mean baseline SOC values given by Dyson *et al*. (2009) have been used to represent the baseline SOC values by land use in northern Europe (modifier) to which the SOC accumulated by implementing C enhancing management options (e.g. incorporation of farmyard manure) are added. Most change in SOC occurs within the top 30 cm of the soil profile (Smith *et al*., 2000ab; Falloon *et al*., 2004) and the calculations undertaken for each modifier refer to this part of the soil profile. The percent change in SOC per year to a depth of 30 cm associated with various land management practices has been calculated using regression equations (Smith *et al*., 2000ab) or from published literature (e.g. Conant *et al*., 2001; Dawson and Smith, 2007; Follet *et al*., 2001; Ganuza and Almendros, 2003; IPCC, 2006; King *et al*., 2004; Ogle *et al*., 2003). Examples of modifiers for accumulation of SOC in cultivated land include incorporation of farmyard manure, straw or the use of grass/clover leys (Ostle *et al*., 2009). Modifiers in grassland include improvements such as fertiliser, liming and mixed swards that contain N-fixing legumes (Conant *et al*., 2001; Follet *et al*., 2001; Ogle *et al*., 2003). The time to reach a new equilibrium is calculated using Equation 1 based on Dyson *et al*. (2009).

$$T = (SOCeqb(new) - SOCeqb(baseline)) / R(SOC) \qquad \text{(Equation 1)}$$

where: T = *Time to establish new SOC equilibrium*
$SOCeqb_{(new)}$ = *potential SOC at equilibrium (t CO2e/ha) of the new land use*
$SOCeqb_{(baseline)}$ = *SOC at equilibrium (t CO2e/ha) of the baseline scenario (current land use)*
$R_{(SOC)}$ = *SOC accumulation rate (t CO2e/ha/year) for a given change in land management*

Where a change in land use occurs (e.g. cultivated to grassland) the potential new SOC at equilibrium is calculated as the baseline of the new land use (i.e. grassland). The above method restricts the 'tentative' model to analysis of changes in SOC between different land uses. It does not allow calculation of changes in SOC within the same land use (e.g. cultivated land) that has undergone management conducive with enhancement of SOC (e.g. incorporation of farmyard manure). The maximum SOC at equilibrium of cultivated land that remains cultivated and its potential to increase SOC (i.e. the maximum additional C that may be added for a given land use and the number of years that the management practice will increase levels of SOC) is currently uncertain. At present the equilibrium attained on mineral soils (expressed as t CO_2e / ha) has been estimated as an additional 5% t CO_2e / ha i.e. by multiplication of the mean SOC in cropland specified by Dyson *et al*. (2009), by 1.05. The estimated figure may be replaced with more accurate data in the future as and when it becomes available. The impact of alteration to management on organic soils is described later. The grassland category used by Dyson *et al*. (2009) assumes the IPCC (2006) definition of all grassland types and includes semi-natural habitat. For European grasslands a distinction exists between grassland that is actively managed as pasture and semi-natural or natural grassland (semi-natural habitat). Pasture includes improved managed grass where the improvement is often ploughing and seeding every five to eight years (Cruickshank *et al*., 1998; Milne and Brown., 1997) reported to reduce the SOC (Conant *et al*., 2001). Carey *et al*. (2008) identify SOC in neutral grassland and improved grassland in England (15 cm deep) as 219.6 and 215.6 t CO2e/ha respectively. An additional SOC category has been created in the 'tentative' model to distinguish improved (ploughed and reseeded) grassland, from permanent grassland. The proportional difference between neutral (assumed as unimproved) and improved grassland identified by Carey *et al*. (2008) has been extrapolated to the mean SOC in grassland identified by Dyson *et al*. (2009) (assumed as unimproved grassland). The SOC in scrub and hedgerow habitats have been categorised as unmanaged grassland. Sequestration in restored peat soils compared to drained habitats has been reported as between 0.37 and 3.66 t CO_2e/ha/year (Dawson and Smith, 2007) although this is an issue of contention with other estimates that no accumulation occurs upon rewetting, at least not immediately. At present the mean of 2.02 t CO_2e/ha/year (Dawson and Smith, 2007) has been used where rewetting of peat soils is selected. This is in addition to prevention of CO_2 loss discussed in a following paragraph. A change in land use from grassland to woodland is predicted by Dawson and Smith (2007) and Ostle *et al*. (2009) to accumulate 0.37 t CO2e/ha year for a period of up to 90 years. If the user chooses to convert grassland to woodland, the sequestration in soil is calculated to increase annually by 0.37 t CO2e/ha. The model also provides the user with additional text to state that accumulation may occur for up to 90 years (i.e. not indefinitely).

In addition to land use and soil type the SOC at equilibrium is dependent on annual precipitation and temperature (Ganuza and Almendros, 2003; Verheijen, *et al*., 2005), factors that impact the SOC at equilibrium for different geographic regions (EU soil carbon database, Undated). They have been accounted for at present using the modifiers 'northern Europe' and 'southern Europe'. For the modifier 'southern Europe' the baseline SOC for each land use has been adjusted using the EU soil carbon database and the method described by Ganuza and Almendros (2003). Further, the modifiers distinguish where management that facilitates C sequestration but risks increased emissions of N_2O or CH_4 has been identified (namely zero tillage in northern European climates) (King *et al*., 2004; Marland *et al*., 2001; Schils *et al*., 2008). In the UK King *et al.* (2004) calculate a net GHG balance for zero relative to conventional tillage of between -0.051 and 0.634 t CO_2e of which -0.308 to -0.664 t CO2e is attributed to the accumulation of additional SOC. Between 0.051 and 0.634 t CO_2e results from increased emission of N_2O because of greater soil compaction. Upon reaching equilibrium, the accumulation of SOC ceases and the GHG balance becomes predominantly additional N_2O.

A priority mitigation strategy identified in northern European Member States (Schils *et al.*, 2008; Smith *et al*., 2008) is the preservation of high C containing peat soils. The magnitude of CO_2 loss mitigated from peat soils is dependent on soil depth and current management. Modifiers include 'drained shallow lowland peat soils' 'drained deep lowland peat soils' and 'drained upland peat soils'. They are estimated to release a mean of 4.0, 10.9 and 7.3 t CO_2e/ha/year respectively (Choudrie *et al*., 2008). A fourth modifier, 'cultivated peat soils', estimates release of 15.0 t CO_2e/ha/year (Freibauer, 2003). Mitigation strategies to prevent further loss of SOC to oxidation include rewetting and, where applicable, removal from cultivation. Where complete rewetting is not possible the restoration of a shallow water table and shallow cultivation may be a potential mitigation strategy (Dawson and Smith, 2007). As an example, the modifier 'remove from cultivation and rewet' on cultivated peat soils will reduce the CO_2 released to zero. Emission of CH_4 from wet peat soils is correlated with depth, from which an estimated 0.5 to 3.8 t CO_2e/ha/year may be emitted (Worrall *et al*., 2003).

3.3.4.12. Carbon: Plant biomass

Biomass contains approximately 50% C (IPCC, 2006). Biomass on farm includes the crop, grass / wildflowers, hedgerows and trees. Taller woody species such as trees contain greater quantities of biomass and therefore C at equilibrium e.g. 513.0 t CO_2e/ha compared to 8.1 t CO_2e/ha for a typical crop rotation (Smith *et al*., 2000ab; Falloon *et al*., 2004). Different vegetation types obtain full biomass potential after different periods of time. The biomass accumulated during a crop rotation or seeding of grassland typically occurs within one year and no further accumulation occurs post year one. The change in biomass C has been calculated as the biomass C of the new land use minus the total biomass C of the previous land use. Vegetation such as woodland requires several decades to reach maturity and maximum C at equilibrium (Milne and Brown, 1997). For this type of land cover the annual biomass C accumulation rate has been calculated as the maximum potential biomass C (i.e. at maturity) divided by the number of years taken to reach that maximum. This assumes a linear annual rate of accumulation although it is acknowledged that this may be affected by the age of the tree and the species (Milne and Brown, 1997). A change in vegetation often results in a change in biomass and C during the first year different to subsequent years. For example, land preparation such as mowing, scrub or tree removal result in an immediate loss of biomass from the land area. The re-accumulation of biomass from the new vegetation cover may then be gradual over several years. The modifiers distinguish between the C accumulated during year one only and for subsequent years. It is calculated as the biomass C of the new vegetation cover accumulated during year one minus the total contained within the previous vegetation cover (the vegetation removed or substituted by the new). The annual biomass C accumulated by the new vegetation only is calculated for the modifiers post year one. It may cause an initial loss of biomass C where a greater quantity of biomass C existed than would be accumulated within the first year by the new vegetation type.

A temptation to improve the C balance of a farm may be to plant woodland on existing productive agricultural land. This may risk displacement of production elsewhere. The modifiers distinguish between increased biomass on existing productive agricultural land or enhancing the biomass on existing non-productive land (e.g. field margins, uncultivated field corners). Where the modifier to increase biomass is existing productive agricultural land the impact on crop yield is taken into account in the economics section. Modifiers for increased biomass C on existing non-productive agricultural land include no cutting of grass, allowing development of shrubby / scrub vegetation, planting of hedges, hedge management (height, laying, replanting gaps), and planting tree strips (Farmer *et al*., 2008). There is no assumed impact on yield.

3.3.4.13. Biomass crops

Biomass cropping includes 'paludiculture', the growing of water tolerant plant species such as reed (*Phragmites* spp) or alder for use as biomass crops on either wet or rewetted peat soils (Wichtman and Joosten, 2007). Used in conjunction with the modifiers that rewet peat soils the biomass C accumulation and energy substitution values of harvested crop have been estimated from those provided by Falloon *et al.* (2004). This option for biomass crops has not been implemented within the 'tentative' model, but there may be scope to do so in the future.

3.4. Task 3: Impacts on other environmental objectives

Activity Start Date	M2	Activity Finish Date	M4
Milestones and Deliverables	Environmental trade-off data indentified.		
Key project partners involved	University of Hertfordshire		

The aim of this task was to supplement data gathered in Tasks 1 and 2 with information on other potential environmental benefits or burdens. Reducing GHG emissions and increasing carbon sequestration are both desirable outcomes. However, within the context of sustainable agriculture, mitigating contributions to climate change is just one objective of many. Other objectives include, for example, minimising the use of non-renewable resources, ensuring water quality, protecting biodiversity, etc. One objective should not be pursued in isolation from, or at the expensive of, other objectives, as this is unlikely to result in a sustainable system. There will inevitably be trade-offs between objectives and compromises will need to be made. However, the important issue is to be able to identify where there are trade-offs and thus select an optimum course of action.

3.4.1. Activity 3.1. Literature and data review

A key part of this work involves identifying where there are trade-offs and synergies between different environmental objectives, so that full benefit and/or cost of any mitigation options can be fully assessed. This part of the literature review has sought to identify actual examples of synergies and trade-offs and how relevant environmental data is being measured and reported. The latter being important to enable data standardisation within the databases embedded in the 'tentative' model.

Some work in this area was reported in the first Interim report. The fundamental work in this area has now been completed. However, as is the case with all the literature and data review and collation work, a continual updating process is being undertaken to ensure that no new developments are missed that could offer value to the project. Identifying quantitative data has been extremely difficult, much of what has been found has been qualitative in nature and so this has affected how the 'tentative' model has been developed (see Section 3.5). A summary of the work undertaken is given below.

3.4.1.1. Air quality

Under the European Community UNECE Convention on Long Range Transboundary Air Pollution (LRTAP) Convention emissions inventory of Europe, each Party to the Convention reports on trends of pollutants pertinent to air quality (European Environment Agency, 2008). It includes NH_3, emissions of which have doubled in the past 100 years owing to greater intensification of agriculture. The EU National Emissions Ceilings Directive specifies NH_3 emissions ceilings for each Member State individually. The emission ceiling for the UK specifies that NH_3 does not exceed 297 kt post 2010. Agricultural sources are estimated to contribute 90% of total European NH_3 emissions (European Environment Agency, 2008). Sources include volatilisation from manure applied to land (particularly slurries when surface applied at higher air temperatures) and during storage, from N excretion by housed livestock, and urine deposition from grazing animals. Emissions also arise from inorganic N fertilisers (especially urea fertilisers) (Chambers *et al*., 1999; Moorby *et al*., 2007). A mean 1.0% of the NH_3 volatilised forms N_2O-N (IPCC, 2006). Greenhouse gas mitigation strategies, for example optimal N application and livestock nutrient use efficiency, reduce emissions of NH_3 (Moorby *et al*., 2007). The application of slurry to grassland during the summer may reduce N leaching however it may increase the NH_3 volatilised. This may be reduced using techniques such as deep injection, a strategy that also maximises the available N to the crop (Chambers *et al*., 1999; Moorby *et al*., 2007).

Other pollutants relevant to agricultural processes and included in the LRTAP Convention are derived mainly from the combustion of fossil fuels. Whilst a reduction in the use of fossil fuels will help mitigate climate change effects there are also potentially other benefits for air quality. Historically elevated levels of smoke and sulphur dioxide (SO_2) that resulted from combustion of fossil fuels containing sulphur (largely coal) were responsible for declines in air quality. Current air quality issues are also attributed to the combustion of petroleum / diesel (e.g. fuel combustion powers tractors that may be used when ploughing or spraying pesticides and pumps to deliver irrigation water (Tzilivakis *et al*., 2005a,b; Williams *et al*., 2006)) and emissions from vehicles. Heating of glasshouse crops may also consume significant quantities of oil or diesel (Körner *et al*., 2007). Another source, dependent on the proportion of fossil fuels used during its generation (and Member State), is grid electricity. Strategies that reduce consumption of these fuels (e.g. adoption of alternative less fuel intensive operations, insulation of buildings) will have a positive impact on air quality. The use of Combined Heat and Power (CHP) to heat glasshouse crops is cited as another method (Caserini *et al*., 2010).

Combustion of fossil fuels may also generate pollutants that may be detrimental to air quality. These and their associated impacts include:

- **Carbon monoxide**: is produced by incomplete or inefficient combustion. Human health effects include prevention of oxygen transport in the blood and reduction of oxygen supplied to the heart. Its main source on farm is operations that consume diesel or petrol such as agricultural vehicles and machinery.
- **Sulphur dioxide (SO_2)**: produced by the combustion of a sulphur containing material such as coal. Electricity generation in a number of Member States includes fossil fuels (mainly coal and heavy oils) as a significant proportion of the mix of grid electricity. Agricultural operations responsible for emission of sulphur dioxide are those that consume large quantities of electricity (mainly post harvest operations

such as refrigeration, operations within dairies and lighting in glasshouse crops (CALU, 2007; Körner *et al*., 2007; Mila-I-Canals *et al*., 2007; Williams *et al*., 2009) if the electricity mix contains a significant proportion of fossil fuels. Direct combustion of coal (e.g. for heating) may result in high localised concentrations of sulphur dioxide that, at moderate concentrations, has potentially detrimental impacts on lung function in asthmatics such that medical assistance is needed. Sulphur dioxide is more harmful as a pollutant in the presence of high concentrations of other pollutants.

- **Nitrogen oxides**: Nitrogen dioxide (NO_2) and nitric oxide (NO) are both oxides of nitrogen and referred to as nitrogen oxides (NO_x). Nitric oxide results from vehicle emissions and fossil fuels combusted during electricity generation. NO_x is also released during volatilisation of inorganic and organic N although this is predominantly NH_3 (IPCC, 2006). Measures to mitigate volatilisation (e.g. avoidance of surface application of manures during the summer) also reduce NO_x (Hodgkinson *et al*., 2002). Nitric oxide is not considered harmful to health but its rapid formation of NO_2 upon release to the atmosphere may cause irritation of the lungs and increase susceptibility to respiratory infections (e.g. influenza).
- **Fine Particles (PM_{10}, $PM_{2.5}$ and PM_1)**: Fine Particles are released during fuel combustion (mainly from vehicles), secondary particles (e.g. sulphate and nitrate that are readily dispersed and transported across national boundaries) and coarse particles (dust, sea salt, biological particles i.e. pollen). They are classified by size (mean aerodynamic diameter) of which PM10 is the main focus of air quality monitoring although PM2.5 and PM1 are becoming increasingly important. The smaller particles (PM2.5 and PM1) may penetrate deep into the lungs and worsen heart and lung disease or transport surface-absorbed carcinogenic compounds. Agricultural management that reduces fuel consumption or environmental release of NO_3^- mitigates atmospheric fine particles. Soil organic matter may be increased by the return of crop residues to the soil as opposed to burning which eliminates air-borne particulates from smoke. (Gomi *et al*., 2004; UK Quality Air Archive, 2010). Strategies that reduce the wind erosion of soil reduce the presence of coarse particles in air.
- **Ozone and volatile organic compounds**: Ozone (O_3) is formed primarily by the action of sunlight on volatile organic compounds (VOCs) in the presence of NO_x. Sources of VOCs include vehicle emissions and fossil fuels combusted during electricity generation, in addition to solvent use, and the distribution and handling of petroleum. Ozone production is dependent on the chemical and meteorological conditions where the VOC is emitted. A particular VOC may produce high levels of ozone where high NO_x concentrations exist, and low quantities where the availability of NO_x is limited. The VOCs that produce radicals during photolytic degradation increase oxidation of any other VOC present and as a consequence, ozone production. A greater intensity of radiation increases the efficiency at which VOCs are able to produce ozone. The ozone creation potential of each VOC is subject to significant spatial and temporal variability (Labouze *et al*., 2004). The formation of ozone over a period of several hours or days means that dispersal over large distances from the source of its precursor molecules is possible, usually downwind. Ozone causes irritation of the airways and agitates the symptoms of asthma and lung disease.
- **Toxic Organic Micro-Pollutants (TOMPS)**: TOMPs arise from the incomplete combustion of fuels, but their constituents although emitted in minute quantities are highly toxic or carcinogenic. No threshold levels exist. Such compounds include: PAHs (Poly Aromatic Hydrocarbons); PCBs (Poly Chlorinated Biphenyls); Dioxins; Furans. Agricultural GHG mitigation strategies to reduce fuel consumed by vehicles and machinery will also reduce TOMPS. TOMPS may be carcinogenic and can result in reduced nervous system disorder immunity (UK Quality Air Archive, 2010).

- **Benzene**: a VOC present in petrol, the combustion of which is the greatest source (70% of total emissions). Impacts on health include cancer, disorders of the central nervous system, damage to liver and kidneys, reproductive disorders, and birth defects (UK Quality Air Archive, 2010).
- **1,3-Butadiene**: a VOC emitted mainly from combustion of petrol and diesel but also used in the manufacture of synthetic rubber. The health impacts are similar to those of benzene.
- **Lead and Heavy Metals**: Currently, the main sources of lead are secondary non-ferrous metal smelters. Small quantities are harmful, especially to unborn and young children where exposure is linked to impaired mental function, visual-motor performance, neurological damage, memory and attention span. (UK Quality Air Archive, 2010).
- **Non-methane Volatile Organic Compounds (NMVOCs):** result mainly from combustion, fossil fuel production and solvents (Friedrich and Obermeier, 1999). A complete inventory of NMVOCs has not been undertaken due to the large number and diversity of compounds (van Aardenne and Gros, 2005). Previously, a major source of these compounds was the burning of agricultural waste however this is no longer permitted in the EU and therefore would be expected to be negligible in Member States. Agricultural GHG mitigation strategies to decrease fuel consumption will reduce emissions of NMVOCs.

The above air pollutants are of relevance to other environmental impacts including human toxicology, ecotoxicology, eutrophication and acidification. Table 3.4.1 provides values from the University of Leiden (2009) LCA characterisation factors database. It includes human toxicity, respiratory effects on humans caused by organic or inorganic substances, carcinogenic effects on humans caused by organic or inorganic substances, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, eutrophication and acidification (including fate, average Europe). Blank cells indicate no value present in the database.

Table 3.4.1: Characterisation Factors

Pollutant	HT	REH	CEH	FAE	MAE	TE	E	A
SO_2	0.096							1.2
NO		1.37E-04					0.2	0.76
NO_2	1.2	6.46E-07					0.13	0.5
PM_{10}	0.82	3.75E-04						
VOCs		6.46E-07						
PAH			1.7E-04					
PCBs			0.00197					
Dioxins	1.9E+09			2.1E+06	3.0E+08	1.2E+04		
Benzene	1830.88		4.12E-06	0.0914	0.0027	1.4E-05		
1,3-Butadiene				3.3E-07	2.7E-06	2.3E-08		

Key: HT (human toxicity), REH (respiratory effects on humans), CEH (carcinogenic effects on humans), FAE (freshwater aquatic ecotoxicity), MAE (marine aquatic ecotoxicity), TE (terrestrial ecotoxicity), E (eutrophication), A (acidification).

3.4.1.2. Soil quality

Soil quality is defined with respect to its ability to perform different functions and indicators based on those of greatest importance including environmental interaction, food and fibre production, support for ecological habitat and biodiversity, the provision of raw materials and protection of cultural heritage (Loveland *et al*., 2002; Merrington *et al*., 2006; Tzilivakis *et al*., 2004). Soils may also act as a buffer/filter to protect groundwater. Desirable indicator values vary depending on the soil type and the function being assessed. A summary is provided in Table 3.4.2 (based on Loveland *et al*., 2002; Merrington *et al*., 2006).

Table 3.4.2: Indicators of soil quality

Soil indicator	
Above ground biomass	Plastic glass/extraneous material
Aeration	PMN
ALC/Land capability	POPs
Biomass indicator	Root penetration
Bulk density	Salinity (EC)/Sodicity
Depth to water logged layer	Seed bank
Earthworms (total number)	Soil borne diseases
Extractable B, Cu, Mn, Se	Soil (horizon) depth
Extractable Ca	Soil water content at 1 m
Extractable K	Soil water storage capacity
Extractable Mg	Soil wetness characterisation
Extractable P	Total N
Extractable S	Total Pb
Macroporosity	Top soil aggregate stability
[1]**Organic carbon**	Total Zn, Cu, Ni, Cd
pH	Wind throw

[1]best stand-alone indicator of soil quality (Milà i Canals *et al*., 2007)

The Communication of the Commission to the European Parliament and the Council “Towards a Thematic Strategy on Soil Protection” in 2002 identified eight priority threats to soil quality: erosion, decline of soil organic matter (SOM), compaction, salinisation, landslides, contamination, sealing and decline in biodiversity. Biodiversity has not been included in The EU Soil Thematic Strategy due to insufficient knowledge to allow for specific provisions (EC, 2006). Each GHG mitigation strategy will be assessed for its impact on each priority threat with the exception of sealing.

Erosion: Erosion of soil, either by water or wind, results in soil loss (Kirkby *et al*., 2004). Soil loss equates to a depletion of a resource regardless of function and reduces its ability to perform the quality indicator functions described by Loveland *et al*. (2002) and Merrington *et al*. (2006). Soil erosion causes a decline in soil organic matter content (Mudgal and Turbé, 2010), the impact of which is dealt with in the following section. It causes reduced plant growth and therefore accumulation of carbon in biomass, and greater emission of CO_2 because the breakdown in soil structure exposes the C within aggregates to air resulting in its oxidation. The erosion of fertile agricultural land is responsible for loss of crop yield. Soil loss and loss of its constituents and associated materials (e.g. organic matter, nutrients, pesticides, heavy metals) also has secondary environmental impacts. These include sedimentation in rivers (that may impact on flooding and fish spawning grounds), eutrophication and aquatic ecotoxicity. These impacts are accounted for within other impact categories within this section. Erosion may also be responsible for compaction and reduced infiltration of water (Louwagie *et al*., 2009). The slow formation of soils resulted in European Environment Agency (1998) and EC (2005) to consider losses in excess of 1 or 2 t / ha respectively irreversible. Losses of up to 20 t / ha have been documented in Southern Spain due to rainstorms (EC, 2006).

The risk of soil loss is site specific and dependent on soil type, local topography (including gradient) and climatic variables such as rainfall. The measurement of actual rates of soil loss is resource intensive, so the risk of loss is therefore assessed using predictive models. Attempts to predict those parts of Europe most at risk to soil erosion have been made by the PESERA model (Kirkby *et al*., 2004). It predicts that the whole of Europe is subject to soil erosion, although the Mediterranean is highlighted as of particular concern. Scandinavia is cited as vulnerable to erosion from rapidly melting snow while Central and Western Europe is at risk to wind erosion and significant loss from water during summer storms. One of the most established predictive modelling techniques to assess soil loss is the Universal Soil Loss Equation (USLE) model (Wischmeier and Smith, 1978) and its derivative, the Revised Universal Soil Loss Equation (RUSLE) model (Renard *et al*., 1998). They estimate average annual soil loss per unit of land area caused by rill and sheet (interrill) erosion. Five variables (annual erosivity of rainfall droplets, risk to erosion of dominant soil type, slope length and steepness, proportion of ground cover, and use of practices such as tillage or soil amendment with e.g. FYM) calculate the average annual soil loss (t) per unit area. The 'tentative' model will not attempt to calculate soil loss. The variables used within the USLE and RUSLE models e.g. absence of ground cover or incorporation of FYM, and their impact on soil erosion, enable prediction of the likely impact of GHG mitigation strategies on soil loss.

The exposure of bare soil to water and wind and lack of SOM promotes soil erosion (Louwagie *et al*., 2009; Mudgal and Turbé, 2010). Maintenance of a cover on the soil surface (e.g. vegetation, residues or green mulch) is a priority of conservation agriculture and a requirement to keep land in good agricultural and environmental condition (GAEC) (Council Regulation (EC) No 73/2009) (Louwagie *et al*., 2009). During 2007 a total of 173,517,040 ha within Europe was either fallow or set-aside (Eurostat, 2010). It reduces the force and energy with which a rain droplet strikes the soil surface and reduces the likelihood of dislodgement of topsoil (Louwagie et al., 2009; Renard *et al*., 1998; Wischmeier and Smith, 1978). It increases SOM and SOC (Louwagie et al., 2009;Smith *et al*., 2000a, b), soil micro-organisms and soil biodiversity (Mudgal and Turbé, 2010; Lal and Kimble 1997; Heisler *et al*. 1998). Prevention of surface run-off improves water quality (Louwagie *et al*., 2009). Ridge tillage alternates cultivated ridges on which the crop is grown, with furrows where residues, or a green mulch, are applied (Louwagie *et al*., 2009). This reduces the area of bare soil and increases the return of organic matter. Another technique to reduce erosion is contour farming where cultivation follows the line of field contours as opposed to the gradient of the slope (Louwagie *et al*., 2009). Surface run-off is reduced on slopes with gradients of less than 10% due to increased infiltration capacity.

Grass buffer strips, when appropriately located (e.g. where they bisect steep gradients), offer potential to reduce the quantity of nitrate and phosphate, and suspended solids that enter watercourses (Louwagie *et al*., 2009). Their location next to watercourses is a requirement to keep land in GAEC. Buffer strips may include hedgerows or trees, the maintenance or planting of which is also a method to enhance C within biomass. The maintenance of landscape features, including hedgerows and olive groves, are compulsory and optional requirements respectively to keep land in GAEC (Louwagie *et al*., 2009). An approach to prevent erosion on steep gradients adopted in Southern Europe is terracing, a series of flat platforms situated along contour lines and held in place by stone walls (Louwagie *et al*., 2009).

Allowing crop residues to remain on the soil surface by using reduced or zero tillage (sections on SOM and soil biodiversity) have been proven to reduce the risk of erosion in maize crops (Louwagie *et al*., 2009). Significant run-off from impermeable materials such as polytunnels is a risk in protected horticultural crops. Collection of rainwater using gutters in order to collect 'grey water' for irrigation is conducive with the prevention of soil erosion.

Soil organic matter (SOM): The USLE and RUSLE models calculate lower rates of soil erosion in response to the maintenance of soil organic matter (SOM), the organic component of a soil (Mudgal and Turbé, 2010). Maintenance of SOM is a requirement to keep land in GAEC (Louwagie *et al*., 2009). It is able to absorb in the region of six times its weight in water (Louwagie et al., 2009) and is essential to maintain soil fertility, structure and porosity, buffering capacity (protection of plants from drastic changes in pH) and sorption capacity (water and plant nutrient retention capacity) (Mudgal and Turbé, 2010). Soil biodiversity (micro-organisms) are also dependent on SOM. The presence of SOM reduces the potential surface water flow and run-off (and with it the transport of soil particles) and improves infiltration. It reduces the vulnerability of soil to compaction and landslides (Louwagie *et al*., 2009) (following sections). A decline in SOM decreases nutrient availability, and soil microorganism biomass and diversity (Pimentel *et al*., 1995). Soil Organic Matter has been recognised as the best stand-alone indicator of soil quality even although it does not fully consider all aspects of soil functioning (Milà i Canals *et al*., 2007). Comprehensive measured EU wide SOM content data has been estimated via modelling (EC, 2006). It predicts that SOM in Europe is decreasing. Southern Europe, where 74% of soil has below 3.4% organic matter (EC, 2006), is highlighted as the main area where low quantities of SOM are present (Louwagie *et al*., 2009). The rate of SOM loss within Europe as a whole is however, currently not available.

Soil organic matter consists of mainly lignins, proteins and cellulose, the IPCC (2006) assumes SOM is 58% C and use a factor of 1.724 to convert weight of SOC to SOM. Agricultural management identified previously that increases SOC also enhance levels of SOM. A greater water retention capacity reduces leaching of NO_3^- (improves water quality and reduces the risk of eutrophication), improves crop N use efficiency (reduces indirect emissions associated with the manufacture of inorganic N that may be leached) and the volume of irrigation water, an energy intensive process. SOM/SOC is a particularly complex issue, for example although it is generally seen as desirable to increase SOM/SOC, the soil cannot accumulate SOC indefinitely and reaches its maximum at equilibrium. The addition of SOM after this equilibrium has been reached results in a net emission of CO_2 (Bending and Turner, 2009; Johnston, 2008). The actual SOC equilibrium for a given piece of land is difficult to predict and influenced by many variables that include soil type, annual rainfall and land management (e.g. frequency of disturbance, incorporation of straw or FYM) (Smith *et al*., 2000 a & b). The mean SOC for a number of soil types and land uses is available for e.g. the UK (Dyson *et al*., 2009) and summarised in Table 3.4.3.

The SOC figures given in Table 3.4.3 may be used to estimate the potential SOC accumulated for a given land use change (e.g. cropland to grassland where accumulation of SOC ceases when the grassland value is attained). It does not allow prediction of the change in SOC within the same land use although for e.g. cropland and improved grassland, the figure will be somewhere between the two values.

Table 3.4.3: Mean SOC (t CO2e / ha) in England (0 – 30 cm) categorised by land use and soil type.

	Organic	Organo-mineral	Mineral	Other	All
Forestland	839.7	447.3	392.3	128.3	337.3
Cropland	623.3	429.0	282.3	106.3	245.7
Grassland	729.7	634.3	352.0	124.7	304.3

Compaction: The maintenance of soil structure (i.e. prevention of compaction) is a further requirement to keep land in GAEC (Louwagie *et al*., 2009). Soil compaction results from the deformation or destruction of soil micro and macro aggregates under pressure (Mudgal and Turbé, 2010) from, for example, the high-axle loads of large agricultural machinery (EC, 2006). Water infiltration is prevented and this increases the risk of water erosion (Louwagie *et al*., 2009). Excessive livestock stocking rates are also cited as a cause of topsoil compaction (Louwagie et al., 2009). Lower stocking rates may still result in localised areas of soil compaction around, for example, feeding troughs (Moorby et al., 2007). The frequent removal of troughs to other parts of the field reduces the risk of compaction and increased emission of N_2O from denitrification. While topsoil compaction may reduce crop yield (because of reduced ability of crop roots to penetrate the soil, and lack of oxygen and water) by up to 13%, it may be in excess of 35% for subsoil compaction, especially when conditions are either very wet or dry (van Camp *et al*., 2004). It is another soil quality indicator of pertinence to agricultural GHG emissions (Moorby *et al*., 2007) where it risks increased denitrification because of the creation of anaerobic conditions within the soil. This favours anaerobic microbial activity and alters the structure of the soil fauna (Mudgal and Turbé, 2010). Soil biodiversity, earthworm populations in particular, is diminished as they are unable to maintain adequate tunnel structures (Mudgal and Turbé, 2010). Measured data of actual soil compaction within the EU does not exist however the susceptibility of soils to compaction is documented, with estimates of up to 36% of European soils as a whole being vulnerable, although it may be greater within individual Member States.

Avoidance of soil compaction is pertinent to mitigating agricultural GHG emissions because reducing the risk of compaction reduces the risk of emission of N_2O from denitrification (Machefert et al., 2002). Identification of farm operations that may cause compaction, and identification of alternatives within the 'tentative' model, may promote both a reduction in GHG emissions, and improvement of soil quality and crop yields. Cowell and Clift (2000) propose a Soil Compaction Indicator (SCI) to assess soil compaction based on the Field Load Index (FLI) (Kuipers and van de Zande, 1994). The weight of vehicles and implements for each operation are multiplied by the time (hours/ha) taken to undertake the operation, and this is then multiplied by the area (ha) on which the operation(s) are carried out. Sub-soiling can help break up compacted layers in the soil, albeit into smaller pieces and not individual aggregates, but it requires more energy than other field operations (Tzilivakis *et al*., 2005a; Williams *et al*., 2009) and in some circumstances deep soil disturbance can be damaging to underlying archaeological features. If management is such that soil compaction is prevented, such operation are not required. The avoidance of machinery operations on wet soils (that significantly reduces the risk of soil compaction) is also identified as a means to reduce the energy consumed by the operation (CALU, 2007). The 'tentative' model identifies a reduction in fuel consumption and GHG emissions, but also a decreased likelihood of soil compaction.

Salinisation: Salinisation is the accumulation of soluble salts (mainly of sodium, magnesium, and calcium) in soils in hot, dry climates where rates of evapo-transpiration may be high (EC, 2006; Louwagie *et al*., 2009). It may be either primary (due to natural processes) or secondary (human induced) (Louwagie et al., 2009). Secondary salinisation arises where poor drainage, excessive or uneven application of irrigation water allows collection of surface water that then evaporates (EC, 2006; Louwagie et al., 2009). It may be increased by addition of salts from using saline water to irrigate agricultural land or the application of inorganic fertilisers to poorly draining land (Louwagie *et al*., 2009). The depletion of groundwater in coastal areas that allows infiltration of seawater (Mudgal and Turbé, 2010) is also a cause. Italy, the Ebro Valley in Spain, and the Great Alföld in Hungary are the main vulnerable areas (EC, 2006).

Salinisation reduces soil fertility and crop yields. It also has detrimental impacts on native vegetation, riparian ecosystems and wetlands. Loss of vegetation increases the risk of desertification (Mudgal and Turbé, 2010). Soil micro-organisms are tolerant up to a certain soil salt concentration but may become dormant and hence inactive if the tolerance threshold is exceeded (Mudgal and Turbé, 2010).

Avoidance of soil compaction (previous section) is conducive with reducing the risk of salinisation (Louwagie *et al*., 2009). The use of drip irrigation is also cited to reduce the risk of salinisation (EC, 2006) because water is delivered directly to the roots and evaporation is reduced. Crop yield is increased simultaneous to water and energy consumption being reduced. Where irrigation is selected, the 'tentative' model identifies drip irrigation as emitting smaller quantities of GHGs during its application. The risk of salinisation under 'other environmental impacts' is also smaller in comparison to, for example, application of irrigation water with a rain-gun.

Landslides: Areas with soils of high erosion risk, a clay sub-soil, steep gradients, heavy rainfall and where land has been abandoned (e.g. the Alpine and the Mediterranean regions) are most susceptible to landslides (EC, 2006). Precise data of total areas at risk within the EU is lacking but over 50% of Italy is classified as being high or very high risk (EC, 2006). Landslides result in Loss of fertile soil, Contamination of soil due to damage to infrastructure such as pipelines and storage facilities, Potential contamination of surface waters with associated off-site costs as described already under erosion, damage to infrastructure (e.g. roads) and potential loss of life, loss of topsoil, leading to a loss of productive soil and hence a decrease in crop yield. Landslides have been mentioned briefly for the purpose of completion, but they are not considered further in the 'tentative' model.

Contamination: Soil contamination, historically a result of industrial processes although currently caused by insufficient pollution prevention and control strategies, is also mentioned briefly but not considered further within the 'tentative' model. When soil is contaminated its functions may be impaired (EC, 2006). Contamination of surrounding land, air and water (including groundwater and drinking water) is also a significant risk. The severity of the impact is dependent on the contaminant itself (e.g. toxicity and persistence within the environment), the area exposed and the concentration of that exposure, and site specific characteristics (e.g. presence of water, susceptible species). The Europe wide mapping of soil contamination has not been undertaken due to lack of data (EC, 2006).

Sealing: Soil sealing through urbanisation results in the creation of a horizontal barrier between the soil, air and the water. It is not considered further.

Soil Biodiversity: General biodiversity issues are included in a section of their own below. However, the focus of this section is soil biodiversity as an indicator of soil quality. Previous sections have identified soil erosion, decline in SOM, salinisation and compaction as detrimental to soil biodiversity with decline in SOM and soil biodiversity being closely linked (EC, 2006). Biological indicator species in soils are grouped by Mudgal and Turbé (2010) as microbial decomposers (microorganisms such as fungi), biological regulators (e.g. springtails or collembola) and soil ecosystem engineers (earthworms, soil dwelling macro-invertebrates such as ground beetles (Carabidae)). Arbuscular mycorrhizal fungi are beneficial species responsible mainly for the transfer of nutrients between the soil and plant, soil aggregation, and protection from soil pathogens and drought stress. Collembola are referred to as regulators because they feed mainly on soil fungi and effectively regulate their populations. Carabids feed on collembola and complete part of their lifecycle as larvae below the soil surface where they too occupy a predatory role but also burrow within the soil.

Different land uses have different quantities of SOC at equilibrium, generally cropland<grassland<forestland (Dyson et al., 2009). For soil biodiversity it is dependent on the species, with greater earthworm populations present in forestland compared to grassland but a lower diversity of biological regulators such as collembola (Mudgal and Turbé, 2010). Boag et al. (1997) and Didden (2001) state that the structure of earthworm communities in grassland compared to cropland does not differ significantly, but abundance is lower in cropland. The agricultural soil community consists of species adapted to regular disturbance (i.e. from tillage). It tends to be devoid of arbuscular mycorrhizal fungi, has fewer earthworms (that maintain soil drainage and facilitate the decomposition of plant material) and collembola (Didden 2001; Heisler and Kaiser 1995; Mudgal and Turbé, 2010). Where microbial communities are sparce, typically in frequently cultivated land, populations of biological regulators also tend to be small (Hodda and Wanless 1994). Loss of microbial decomposers and earthworms stifles nutrient cycling, decomposition of SOM and carbon accumulation. The number of carabid beetles is also adversely affected by increased tillage frequency and depth where high mortality may be caused to larval stages.

Strategies that reduce the frequency or depth of tillage increase SOC (and SOM) within cropland (that remains as cropland) and include grass leys and reduced, minimum or zero tillage. Conservation agriculture combines reduced tillage with maintenance of surface cover and diverse crop rotations which are generally beneficial to soil biodiversity (Louwagie et al., 2009). Intercropping is a further technique to increase crop diversity and soil biodiversity. The application of FYM is cited by (Birkhofer et al. 2008) to increase biological regulator abundance (e.g. bacterivorous nematodes) and ecosystem engineers such as earthworms in the soil and carabid beetles above ground. Maximising the N in FYM (and the inorganic N it substitutes) depends on timing and rapid incorporation post application. Tillage is therefore a requirement that, as identified previously, may be detrimental to soil biodiversity. Organic matter also increases in response to the incorporation of crop residues or stubble (Mudgal and Turbé, 2010) however this also requires that tillage be undertaken. Deriving N from waste materials like sewage sludge is another potential method to substitute inorganic N. It has however been found to reduce soil invertebrate communities (Andres and Domene 2005; Pavao-Zuckerman and Coleman 2007).

3.4.1.3. Water quality

Water quality is the focus of a number of EU Directives. Of particular relevance to agriculture is the Nitrates Directive (Council Directive 91/676/EEC) that aims to reduce and prevent the pollution of water from nitrates from agricultural land. In combination with the Urban Waste Water Treatment Directive it aims to prevent eutrophication and potential impacts on health from excessive nitrates in drinking water. Monitoring of nitrate concentrations and trophic status of water, identification of waters either in excess of or at risk of breaching the permitted quality threshold (50 mg/l), and the designation of the surrounding land of these waters as Nitrate Vulnerable Zones (NVZs) are mechanisms by which a MS is required to implement the Nitrates Directive. Others include formulation of Codes of Good Agricultural Practice and Action Programmes.

Council Directive 98/83/EC, the Drinking Water Directive (DWD) sets standards for a total of 48 microbiological and chemical parameters (substances commonly found in drinking water) that require frequent monitoring and testing. Those of pertinence to agriculture include *Escherichia coli* (*E.coli*) (contamination with manures or slurries), nitrate, individual pesticide active ingredients (where reporting is limited to only individual pesticides identified above the limit are reported), total pesticides and total organic carbon (TOC). The EC (2010) reports parameters that are most frequently non-compliant within the EU as:

- Iron and manganese
- Coliform bacteria
- Aluminium
- Enterococci
- Colony Counts 22
- Arsenic, nitrate, THM (trihalomethanes), sulphate
- Lead, nickel, PAH (polycyclic aromatic hydrocarbons), chloride, pH and turbidity.

The pesticides atrazine and desethylatrazine are also highlighted as issues by several MS's.

The Water Framework Directive (WFD) (2000/60/EC) uses river basins as the geographical and hydrological unit, as opposed to administrative or political boundaries. The water quality of a river in one MS may be impacted by the actions of another MS through which it has passed previously. The Directive applies to inland surface waters, transitional waters, coastal waters and groundwater. Water quality, and compliance with the Directive, is measured by 'good ecological status' and 'good chemical status'. Groundwater quality is also measured by its 'quantitative status'. Member States must achieve good status for all waters (including groundwater) by 2015. The measurement of biological quality is not straight-forward because no absolute standards applicable across the EU can be set, due to ecological variation both within and between types of water body (e.g. the biological community of a river near its source may be significantly different to that further downstream). There are five water quality status categories: high, good, moderate, poor and bad. A baseline biological community (the reference condition), typical of where there is minimal anthropogenic impact, represents a water body of 'high status'. Any deviation from this community represents a decline in water quality. Depending on the magnitude of this deviation it may be downgraded to 'good status' (where there is a small deviation), or as 'bad status' where there is a significant deviation. The reference conditions are specific for different types of rivers, lakes or coastal waters in order to account for the ecological diversity across regions of Europe.

Water quality is classed as having good chemical status where there is compliance with all European quality standards for chemical substances. The WFD outlines a requirement to reduce the concentrations of a number of 'priority' and 'priority hazardous' substances. Annex II of the Directive on Priority Substances (Directive 2008/105/EC) specifies maximum concentrations in surface waters of 33 priority substances (plant protection products, biocides, metals and other e.g. Polyaromatic Hydrocarbons). A further 8 substances, that fall under the scope of Directive 86/280/EEC List I Daughter Directive to DSD (consolidated), are also included. Groundwater has been subject to more rigorous standards since it used as drinking water and therefore the presence of any chemicals not permitted. A small number of limits e.g. pesticide concentrations in water supplies for the extraction of drinking water should not exceed 0.1 ug l^{-1} have been established. Direct discharges to groundwater are prohibited.

Agricultural production may impact on water quality in a number of ways. They include:

- **Nutrient loss:** from inorganic N fertiliser and livestock manures and slurries, exacerbated by application of excessive quantities or at inappropriate times of the year, can enter and have a significant impact on both surface and groundwater. Surface waters may be contaminated via run-off, sub-surface flow and field drains; groundwater by leaching and percolation. Nitrogen tends to move in solution as NO_3^- where it is not readily retained by soil colloids and therefore moves rapidly through the soil profile when in the presence of e.g. rainwater. Phosphate binds with the soil and its dispersal into water is therefore associated more with soil erosion. A consequence is eutrophication and decline in biodiversity because firstly, a limited number of species are favoured, and secondly due to depletion of oxygen from the Biological Oxygen Demand (BOD) of organic material and the increased populations of algae. Nitrate may cause risk to human health (e.g. methemoglobinemia). The GHG mitigation strategies identified are considered within the 'tentative' model with respect to their potential to increase water pollution. For example, the optimisation of N applied as crop nutrients decreases leaching of NO_3^- into water and the indirect emission of N_2O (IPCC, 2006). The potential to increase water pollution is therefore negative.
- **Pesticide contamination:** Pesticides may enter surface waters via run-off, drift, sub-surface flow and field drains either in solution or adsorbed to soil particles). Groundwater may be contaminated from leaching and percolation, which affects drinking water quality, aquatic ecosystems and biodiversity (Skinner *et al*., 1997). Small quantities of active ingredient may have significant detrimental impacts on water quality and breach limits specified by the WFD. Although there are indirect GHG emissions associated with the manufacture of pesticides (Green, 1987), those associated with the small quantities of active ingredient typically applied per unit of production are relatively minor in comparison to, for

example mineral N fertiliser (Williams *et al*., 2009). Improvement to water quality by optimisation of pesticide usage is unlikely to have a significant impact on GHG emissions pre farm gate, with the exception of soil fumigants.

- **Use of water resources:** The abstraction of water from surface waters (e.g. for irrigation, dairy cleaning, watering cattle, washing produce, etc.) may impact on the chemical composition and biodiversity of rivers, particularly during periods of unusually low flow (i.e. irrigation during the summer). Over abstraction in coastal areas also risks contamination of groundwater with saline water. Optimising water use to minimise the amount abstracted (positive impact on water quality) reduces the quantity applied via e.g. irrigation, an energy intensive process, that may significantly reduce GHG emissions.
- **Pathogen contamination:** Contamination of surface water (via run-off and sub-surface flow) or groundwater (via percolation) with slurries and manures may result in increased populations of micro-organisms with consequent impacts for drinking water quality, aquatic ecosystems and biodiversity. Risks are increased by the spreading of manures or slurries near surface water, or during unfavourable weather conditions or where soil conditions are unsuitable. It may also be a result of leakage from storage systems.

Direct methods to assess the impact of agriculture on the quality of surface and groundwater include the sampling and monitoring of chemical (including nutrient), biological and/or micro-biological, or a combination of the two. The key methodology used in the EU has been outlined previously in the paragraph describing the WFD. The system of monitoring (classification) used in the WFD is risk-based and concentrates monitoring effort on locations deemed to be of greatest risk. It also uses the poorest individual sample result for a given sample location in the overall assessment. A much greater range of parameters are assessed in comparison to methods used previously. Although covering a broad range of parameters, in practice it may be difficult to attribute the data obtained from monitoring to specific farms or practices due to the interconnectivity of catchments, and the length of a river basin. Regular monitoring networks are also relatively sparse and generally placed at the downstream end of catchments (or sub-catchments), meaning that unless further investigation is carried out, it is difficult to be specific about the location of the cause of an identified impact. The monitoring of nitrate concentration is also a requirement of the Nitrates Directive, and trends in nitrate concentrations within individual MSs have been, and are still required to be, reported every four years (EC, 2010). Groundwater monitoring revealed nitrate concentrations as either stable or smaller in 66% of sample locations, while in fresh surface water, 70% of sample locations experienced a decrease or had remained stable (EC, 2010). The introduction of certain practices e.g. closed periods for the application of slurries with high readily available N within NVZs, are one practice correlated with decreased environmental N loss via leaching, and an associated improvement in water quality (decreased nitrate). Decreased leaching of NO_3^- is coupled with reduced emissions of N_2O (IPCC, 2006). The GHG mitigation strategies identified in the 'tentative' model are considered with respect to their potential to increase water pollution. It is possible to score such practices as reducing GHG emissions while not having a negative impact on water quality, with reasonable confidence.

3.4.1.4. Biodiversity

Biodiversity covers a broad range of issues of relevance to agricultural management and include aquatic and terrestrial ecosystems, invertebrates, plants, birds and mammals (e.g. Henle *et al*., 2008; Natural England, 2010; Stoate *et al*., 2009). Those considered of greatest importance on which the review will focus include:

- Physical disturbance habitats and ecosystems, e.g. woodland clearance, hedgerow removal.
- Degradation of habitats and ecosystems, e.g. eutrophication and acidification
- Eco-toxicological effects as a consequence of exposure to pesticides

The impacts of agricultural activities on biodiversity are known more concisely for some species, for example farmland bird numbers are well documented and recorded (Defra, 2009a). Impacts on populations of species are however derived from national or regional monitoring programmes and not directly associated with any particular one farm. Some farms survey and monitor wildlife on their farms, e.g. those which have a personal interest in conservation or in some instances as part of a scheme but are not representative of the majority of farms. Alternative techniques are available to assess potential impacts and include Ecotoxicity; Eutrophication (aquatic and terrestrial); Acidification and qualitative scoring systems, e.g. AMY (the Agrobiodiversity Management Yardstick). These are discussed below.

Ecotoxicity: An ecotoxicological effect is an adverse change in the structure, or function, of a species as a result of exposure to a chemical. It is an area of complexity and involves understanding the exposure of different organisms to different substances and the hazard such an exposure presents to that organism. A range of parameters exist that aid the hazard and risk description. For example, the LC_{50} may be used to describe the hazard posed by a chemical to aquatic organisms such as fish. This is the substance concentration hat is lethal to 50% of the fish population within a set period of time (often 96 hours). Similarly for terrestrial organisms such as mammals the acute oral LD_{50} is the dose (often as mg per kg of body weight) that is lethal to 50% of the population. Other parameters include the EC_{50} (the concentration of a chemical that can be expected to cause a defined non-lethal effect in 50% of the tested population), and NOEL/NOEC (the greatest concentration or level of a chemical, found by observation or experiment, which causes no detectable effect). Using these measures, it is then possible to determine what the risk might be for a number of different species in different environments for a given concentration of a chemical (e.g. a pesticide).

To determine the ecotoxicological effects and risks via an environmental assessment, the amount of chemical emitted to (and, ideally, the concentration in) a particular environmental compartment needs to be known, then the relevant toxicological threshold (e.g. LC_{50}, LD_{50}, EC_{50}, etc.) can be used to determine the likely risk posed to different organisms. The determination of active ingredient emissions of substances can be very difficult, let alone their consequent concentration in the environment. Diffuse emissions can occur over a long period of time and are dependent upon localised soil and weather conditions and complex models are required to quantify environmental releases. Models to determine the fate of different pollutants in the environment include dispersion models used in air quality assessments (e.g. CAR-FMI (Härkönen *et al*., 1995); UDM-FMI (Karppinen *et al*., 2000); FLEXPART (Stohl *et al*., 1998)), or fate and transport models for pesticides applied to field crops e.g. FOOTPRINT (Dubus *et al*., 2009). Modelling allows a more detailed taxa based risk assessment e.g. a pesticide toxic only to fish that degrades rapidly in the crop and soil poses a low risk to biodiversity. If the molecule is persistent (does not readily degrade) and is easily washed into a water body, then the risk to fish is potentially high.

Modelling the fate and environmental concentration of every pesticide active ingredient used is an onerous task. It may not be practical and/or reliable models may not exist or be publically available. Characterisation factors have been developed to simplify the ecotoxicological impact assessment process. They include expressing emissions of active ingredients in 1,4-dichlorobenzene-equivalents (Huijbregts, 2001) or triethylene glycol equivalents (Jolliet *et al*., 2003b) in a similar fashion to CO_2 equivalents used for GWP. Another approach is the USETox™ model and database (Rosenbaum *et al*., 2008). The USETox™ model utilises Potentially Affected Fractions (PAFs) as the characterisation factor. It aims to reflect the toxic stress on an ecosystem, so incorporates an element of species sensitivity and exposure into the characterisation factor.

Agricultural biodiversity has been linked with decreased use of pesticides, or rather specific pesticide active ingredients toxic to key non-target beneficial species (insects or arachnids) and other non-target species such as birds and mammals (Lewis *et al*., 1997). The use of pesticides do not in general contribute significantly to GHG emissions within agriculture and their use therefore not subject to GHG mitigation strategies. From the perspective of reducing the impact of pesticide ecotoxicity, the substitution of specific active ingredients with less toxic alternatives will have a negligible impact on agricultural GHG emissions. Strategies to reduce pesticide application include the spatial targeting of pesticides within the crop (Warner *et al*., 2008). This may also reduce fuel consumption and the associated GHG emissions due to a potentially smaller proportion of the crop being treated. Soil fumigants used in certain horticultural crops are applied in large quantities and strategies to reduce their use (long crop rotation or soil testing and targeting) do offer potential to make a more significant contribution to the GHG balance of fumigated crops (Warner *et al*., 2010). As discussed in previous sections, the risk posed by an active ingredient is not solely its toxicity but also its presence in time and space within the crop. The application of fumigants to the entire top soil profile has highly negative impacts on soil dwelling fauna that may otherwise not be affected by conventional pesticide sprays that may only impact the soil surface. Earthworms and ground beetle larvae are examples of species that would benefit.

Eutrophication (aquatic & terrestrial). Eutrophication may be termed as aquatic or terrestrial. Aquatic eutrophication results from nutrient enrichment (N or P) in aquatic environments resulting in increased algal growth, water turbidity and decreased levels of oxygen (Environment Agency, 2004). Mortality of aquatic fauna (e.g. fish) may then occur, leading to an ultimate loss of biodiversity (Kristensen and Hansen, 1994). Increased loads of P are mainly responsible for eutrophication of freshwater. In saline estuarine habitats it tends to be nitrate. Terrestrial eutrophication is the nutrient enrichment of soils. Exposure of nitrogen-limited ecosystems to increased nitrogen loads often increases the competitive advantage of previously nitrogen limited plant species at the expense of those species adapted to low nitrogen containing soils.

The potential of a compound to cause eutrophication is expressed as kg PO_4^--equivalents and kg NO_x-equivalents for aquatic and terrestrial eutrophication respectively (University of Leiden, 2009). Table 3.4.4 shows the method applicable to aquatic eutrophication. A comprehensive database of mean Europe eutrophication factors is provided by the University of Leiden (2009). Brentrup *et al*. (2004) also provide regionalised characterisation factors for terrestrial eutrophication. For example, in the UK 1 kg NO_x emitted = 0.76 kg NO_xe and 1 kg of NH_3 emitted = 1.70 kg NO_xe (the reference region is Switzerland, where the factors are 1.00 and 5.00 respectively). Brentrup *et al*. (2004) use normalisation values.

Table 3.4.4: Aquatic eutrophication impact sub-category: characterisation factors for N and P emissions.

Compound (kg)	N	NH_3	NH_4	NO_x	NO_3	NO_3–N	P	P_2O_5	PO_4
kg PO_4-equivalent / kg	0.42	0.35	0.33	0.13	0.10	0.42	3.06	1.34	1.00

Agricultural sources of significance include NO_3^- from inorganic and organic fertiliser use and phosphate PO_4^- from surface run-off and soil erosion. Emission of ammonia (NH_3) to air results from urea based fertilisers and livestock manures, liquid manures in particular. The magnitude is dependent on the method of storage, and timing and method of application (e.g. surface or injection) of liquid manures to agricultural land. The mitigation of NO_3^- and NH_3 both reduce emissions of N_2O (IPCC, 2006). Strategies to mitigate loss of NO_3^- include greater N use efficiency and optimal timing of inorganic and organic N application (MAFF, 2000). The mitigation of NH_3 includes avoidance of surface manure application during the summer (MAFF, 2000) and selection of appropriate manure management strategies (e.g. covering slurry) (Hornig *et al*., 1999). They also reduce odour. The prevention of soil erosion and run-off reduces deposition of particulates and N and P into water courses.

Acidification: An increase in acidity (hydrogen ion concentration) in water and soil systems results in acidification. It is caused by sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). Acid deposition has negative impacts on terrestrial and aquatic ecosystems including primary production, fish production capacity, base cation capacity of soils, and contribution to species extinction. The actual impact will vary from one region to another according to the deposition pattern and the susceptibility of the receiving area to acidification. Emissions of SO_2, NO_x and NH_3 are standardised through conversion to SO_2 equivalents. In a manner similar to terrestrial eutrophication, different characterisation factors exist for different regions to reflect the different deposition pattern and the susceptibilities to acidification. For example, in the UK 1 kg of SO_2 = 0.86 kg SO_2e, 1 kg of NO_x = 0.43 kg SO_2e and 1 kg of NH_3 = 1.5 kg SO_2e (Brentrup *et al*., 2004).

Emission sources of relevance to agriculture include SO_2 from the combustion of sulphur-containing coal and oil (electricity from the national grid in some Member States), NO_x from combustion of fuel by vehicles, and NH_3 from manures and volatilisation from the application of inorganic N fertiliser and organic manures (IPCC, 2006). Agricultural GHG mitigation strategies that reduce electricity consumption (e.g. modification of post harvest operations, use of 'grey water'), reduce fuel consumption (e.g. alternative field operations, irrigation strategies to reduce water) and techniques to minimise volatilisation of NH_3 (e.g. timing and method of organic manure application) will also reduce acidification.

The impact categories of ecotoxicity, eutrophication and acidification provide a relative scale (i.e. equivalents) of how a particular molecule contributes to that process. Actual quantification of the impact of these processes on biodiversity, having calculated the potential of an agricultural operation to contribute toward that process, is difficult in the absence of site specific monitoring data. One approach to overcome this, considered in developing the 'tentative' model, is to create a scoring system for various activities and practices that should (or can) result in positive (or negative) impacts with respect to biodiversity. An example of this would be the Agrobiodiversity Management Yardstick (AMY) developed in the Netherlands (van Amstel *et al*., 2007a,b).

The **Agrobiodiversity Management Yardstick** uses a ladder of abstraction (Sartori, 1991) to create links between agrobiodiversity policy goals and the concrete level of management measures on a farm. Figure 3.4.1 (from van Amstel *et al*., 2007a) shows 4 levels of abstraction, with the 5th level containing about 140 on-farm management measures that positively affect agrobiodiversity. Expert judgement is used to construct the abstraction and score each management practice for its efficacy in relation to the positive impact on agrobiodiversity and the extent to which it contributes to conservation and sustainable use of agrobiodiversity.

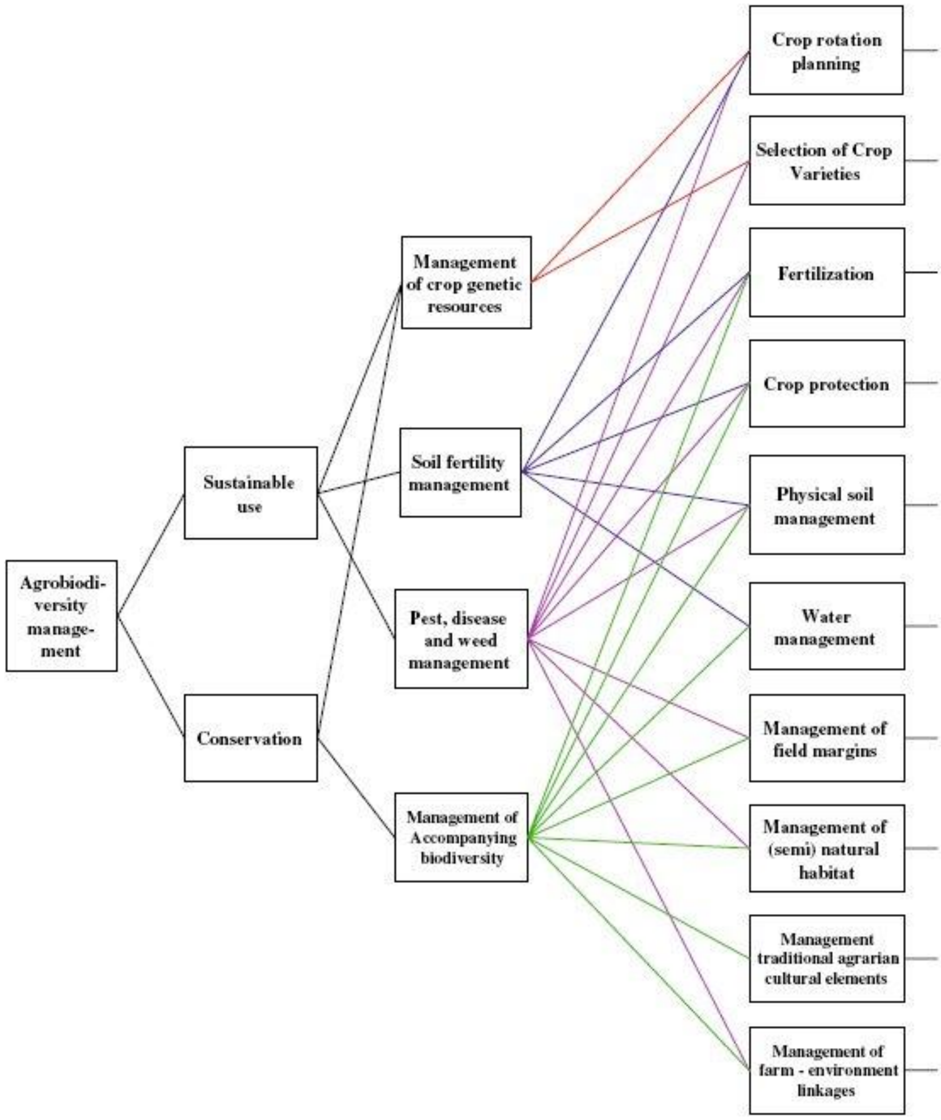


Figure 3.4.1: The AMY, the first four levels of abstraction

A criticism of the AMY approach is its tendency to account only for positive impacts. An alternative scoring approach but with some similarities has been developed by Lewis *et al*. (1997) to score and rank farmland conservation activities. An 'eco-rating' system is used where the normalised score ranges from -250 to +250, capturing both negative and positive management practices.

Agricultural GHG mitigation strategies that have a direct impact on biodiversity (i.e. independently of / in addition to reduction of ecotoxicity, eutrophication and acidification) include use of clover as a cover crop to provide ground cover for invertebrates such as predatory beetles, collembolans and arachnids. This increases the diversity of soil dwelling species while providing food for insectivorous farmland birds. An increase in soil organic matter increases the diversity and abundance of soil dwelling invertebrates such as collembolans and earthworms because potential food sources (e.g. fungi) also increase (Henle *et al*., 2008; Stoate *et al*., 2009). This then supports greater populations of predatory invertebrates (e.g. carabid beetles). Uncropped field boundaries with vegetation cover provide 'wildlife corridors' and refuges for fauna and flora within the agricultural landscape (Stoate *et al*., 2009).

Activity-Effect-Outcome (AEO): IMPACCT will in part utilise the Activity-Effect-Outcome database from Defra project IF0131 (Tzilivakis *et al*., 2009) to identify possible consequences for biodiversity that each GHG mitigation strategy may have. The AEO database identifies the potential outcomes of an activity or group of activities (top-down), or the activities that contribute to a particular outcome (bottom-up). Similar to the AMY system, this database uses scoring techniques to indicate potential impacts, in this instance, on biodiversity.

The 'Activity' in the AEO database of interest in this case is the management strategy that mitigates GHG emissions, the 'Outcomes' are its impact on biodiversity. The following outcomes will be scored within the IMPACCT software in response to each management activity: farmland birds, mammals, plants, invertebrates and aquatic organisms.

Farmland birds, certain invertebrate groups (e.g. butterflies) and plants are included in Defra's Observatory Programme Indicators (Defra, 2009 a, b and c). The effect on aquatic organisms will incorporate broader impacts such as eutrophication. Soil biodiversity will be considered separately as an indicator of soil quality.

3.4.1.5. Stratospheric ozone depletion

Depletion of stratospheric ozone has been observed since the 1970's, with the most noticeable effects in the southern hemisphere and over Antarctica. Stratospheric ozone reduces the quantity of ultraviolet light (wavelength ~300 nm) reaching the Earth's surface and exposure to UV radiation (Jolliet *et al*., 2004; UNEP, 2003). Impacts of ozone depletion have focused on human health, especially increases in skin cancer and cataracts. Impacts of pertinence to agriculture include crop damage (Jolliet *et al*., 2004) and damage to polyethylene materials (reduced lifespan of polytunnel covers) (Warner *et al*., 2010).

Molecules primarily responsible for stratospheric ozone depletion include chlorine and bromine-containing substances (halocarbons) e.g. chlorofluorocarbons (CFCs), halons, and hydrochlorofluorocarbons (HCFCs) in addition to methyl chloroform, carbon tetrachloride and methyl bromide (Derwent *et al*., 1998; 2007). The midpoint impact category for stratospheric ozone depletion is Ozone Depletion Potential (ODP) that standardises different molecules on the same scale, kg CFC-11 equivalents (Table 3.4.5) (IEC, 2008; University of Leiden, 2009).

Table 3.4.5: Ozone Depletion Potentials

Species	Formula	ODP [kg CFC-11 eq./kg]
Bromo-methane	CH_3Br	2.30
CFC-11 (Trichlorofluoromethane)	$CFCl_3$	1.0
CFC-113	$C2F_3Cl_3$	0.59
HALON-1211	$CClF_2Br$	9.0
HALON-1301	CF_3Br	10.50
HALON-2402	$C_2F_4Br_2$	11.0
HCFC-123	$CHCl_2CF_3$	0.08
HCFC-124	$CHFClCF_3$	0.08
HCFC-141b	CH_3CFCl_2	0.33
HCFC-142b	CH_3CF2Cl	0.14
HCFC-22	CHF_2Cl	0.14
HCFC-225ca	$C_3HCl_2F_5$	0.10
HCFC-225cb	$C_3HCl_2F_5$	0.11
Tetrachloromethane	CCl_4	1.23
Trichloroethane	CH_3CCl_3	0.45

Detailed life cycle assessments usually include the ODP of a product, for example crop production (Defra, 2008) or specific products such as polyethylene (Bousted, 2003). The use of products containing these molecules is now largely prohibited. For agricultural products the main contributors were previously soil fumigants that have been either banned (e.g. methyl bromide) or are being phased out (e.g. chloropicrin). Refrigerants are also potential sources during post harvest storage and processing. The importance of this impact category is thought to be diminishing (Pennington *et al*., 2004).

3.4.1.6. Resource use

Resources may be divided into biotic and abiotic and/or renewable or non-renewable and include:

- Fossil fuels (energy derived from)
- Minerals and elements (e.g. metals, phosphates, etc.)
- Water
- Soil

A number of techniques have been developed to assess depletion impacts (of different resources) on a common scale, rather than simply listing the consumption of every resource used in the life cycle of a product. One approach, the CML method (Guinée, 2001), aggregates different resources using their Abiotic Resource Depletion Potential (ADP), where antimony is used as a reference substance (ADP is expressed in kg antimony-equivalents), based on the scarcity of reserves. However, Brentrup *et al*. (2002) highlight that this neglects that many resources are used for different purposes and are not equivalent to each other. Therefore, the depletion of reserves of functionally non-equivalent resources should be treated as separate environmental problems. Brentrup *et al*. (2002) develop the concept grouping resources based on their function, e.g. the use of oil, natural gas and coal as energy sources, and then expressing use of those resources in MJ, as a means of aggregating the impacts.

Energy from fossil fuels: Significant users of energy (and potentially fossil fuels) within agriculture include heating glasshouse crops (Körner *et al*., 2007; Williams *et al*., 2009), the manufacture of nitrate fertilisers and polyethylene (e.g. for polytunnel covers or mulch) (Warner *et al*., 2010), irrigation (Dalgaard *et al*., 2001), milking dairy cows (and associated cleaning), drying of grain, refrigeration of potatoes or fruit (CALU,

2007) and deeper tillage operations on heavy soils (Williams *et al*., 2009). The depreciation of machinery is also worthy of consideration where an operation results in frequent damage to and replacement of machinery parts (e.g. broken tines) (Hulsbergen and Kalk, 2001). A reduction in either energy use / increased efficiency of use or reducing the energy derived from fossil fuels (on farm renewable electricity generation) decreases agricultural GHG emissions (Tzilivakis *et al*., 2005 a,b; Warner *et al*., 2010; Williams *et al*., 2006; 2008; 2009). Energy conservation is paramount in heated glasshouse crops (Korner *et al*., 2007) and through maximising the lifespan of materials (e.g. LDPE) subject to energy intensive production processes (Bousted, 2003; Warner *et al*., 2010).

Minerals and elements: Phosphate reserves are depleting rapidly, prevention of soil erosion (closely linked with the mitigation of eutrophication) and application of manures (a method to increase SOC and reduce the risk of erosion) are methods for its conservation. Depletion of metals arises during the depreciation of agricultural machinery (replacement parts) and structural requirements (e.g. steel for polytunnels or glasshouses). The replacement of older machinery with new machinery improves the fuel consumption efficiency however a new machine is a significant investment in abiotic resources. The maximisation of the lifespan of a machine versus optimising fuel efficiency through purchase of a new represents a potential environmental trade-off.

Water: The significance of the water resource consumed varies spatially and is related to water availability. Improvements to resource use efficiency do not necessarily reflect the impacts of resource use, especially with respect to the use of significantly depleted reserves or where there are local issues, such as water scarcity. In these instances production can still have high efficiency, but still be drawing upon resources in an unsustainable fashion. The conservation of water is conducive with reducing fossil fuel consumption during both its treatment (Wessex Water Ltd, 2004) or desalination, and application via irrigation (Dalgaard *et al*., 2001). A number of soil management strategies to enhance soil water holding capacity or reduce water loss have been proposed by Debeake and Aboudare (2004). Increased SOM (also increases SOC, a benefit), reducing soil evaporation by leaving residues on the surface (risks a decline in the SOM and SOC), minimum tillage (also decreases fuel consumed by machinery but may increase soil N_2O in northern Europe), maximising water extraction by the crop roots through deeper tillage to improve rooting depth (will be some increase in the fuel consumed by machinery but nullified by the reduction in fuel for irrigation described in previous sections), minimising / eliminating soil drainage (risks increased denitrification although not such an issue where rainfall is lower).

3.4.1.7. Waste and recycling

Waste in this context refers to man-made materials and it does not include organic manures. Waste and recycling are often examined within many environmental assessments. However, they are not necessarily impacts. In the context of the lifecycle of a product or process, waste is either an emission (and thus handled within other impact categories) or a by-product. Similarly, recycling is an activity to handle any such 'emissions' or by-products that arise, and thus placing less demand on 'virgin' resources, and so this would be encompassed under the resource impact category.

Waste in agriculture includes pesticide and fertiliser containers but is of greater relevance to protected horticultural crops that utilise large quantities of plastics to cover polytunnels and use as a mulch or as bags to contain growing media (Warner *et al*., 2010). Maximising the lifespan of materials, such as polyethylene used for polytunnel covers, is cited as a GHG mitigation strategy since emissions per year of use are reduced. It also reduces waste and the energy (resource) used to create the virgin material.

3.4.1.8. Landscape and heritage

Landscape and heritage impacts cover aesthetic and archaeological/historic issues respectively. Impacts can be site specific and can often have a high public awareness. They have been grouped together as, although they are both important with respect to public interests, they do not necessarily have any correlation to ecosystem functioning – although in some instances (but not all) a diverse and scenic landscape can often have benefits for biodiversity as well. For example, the loss of hedgerows and stonewalls during the 20th Century due to agricultural intensification had both impacts on biodiversity and wildlife and on the landscape. The importance of landscape and heritage is also reflected in EU and UK agricultural policy, for example many of the options within environmental stewardship schemes and some of the regulations in cross compliance are designed to bring about benefits with respect to enhancing and protecting landscapes and preserving archaeological features. The impacts can be difficult to quantify, especially within the framework of a life cycle assessment for a product. However, some (e.g. Haas *et al*., 2000) have attempted to incorporate landscape elements into the assessment process, usually via a scoring technique.

Landscape features include ancient woodlands, veteran trees, hedgerows and stone walls. The former three both contain C within biomass and their preservation conducive with maintenance of biomass C and sequestration (Falloon *et al*., 2004; Warner *et al*., 2008). The effect the creation of woodlands and hedgerows has on the GHG balance of crop production depends on the location. Removal of productive agricultural land to enhance landscape features has implications for the displacement of production. It is unlikely to be an issue with hedgerows or tree strips if created on existing boundaries. Where archaeological features are present within fields and the land is maintained within production they may be managed by shallow or zero tillage (Natural England, 2008). In northern European climates where precipitation is greater, zero tillage has been attributed to increased emission of N_2O from soils. The management of archaeological features in certain climates therefore may not be sympathetic to agricultural GHG mitigation.

3.4.1.9. Public safety and nuisance

Issues of public safety and nuisance include noise, odour and pathogens (*E. coli*). Flooding (e.g. from excessive surface run-off on steep gradients) is a further potential, albeit site specific, impact. Haas *et al*. (2000) excluded the impact category of nuisance (noise and odour) from agricultural production because of its subjective nature, stating that "agricultural smell and sound are part of the rural image in rural areas and perceived indifferently by the people". Udo de Haes *et al*. (1999) and Zobel *et al*. (2002) consider noise and odour under human toxicity although neither author proposes a method for their quantification. The impact of road traffic noise on human health was assessed by Mueller-Wenk (2002) and Jolliet *et al*. (2003a) propose expression of traffic and/or industrial noise measured as an equivalent intensity of noise over certain decibel threshold, per individual. The quantification of odour has been undertaken by Guinée (2002) using the 1989 Dutch Malodourous Air Thresholds as a basis for constructing impact factors.

Noise emanates from machinery, refrigeration, storage and transportation. Agricultural GHG mitigation strategies may reduce the number of machinery operations and their associated noise. Agricultural sources of odour are predominantly livestock related, specifically manure storage (Hornig *et al*., 1999). Anaerobic digestion and the covering of slurry stores, both potential GHG mitigation strategies (Hornig *et al*., 1999; Monteny *et al*., 2006; Sommer *et al*., 2007), also reduce odour. Anaerobic digestion has the capability to remove a third human health issue, pathogens such as *E. coli*. The prevention of soil compaction to reduce emission of N_2O (Bouwman *et al*., 1996; Moorby *et al*., 2007) also reduces the risk of excessive water surface run-off and potential risk of flooding. The prevention of soil erosion by wind (e.g. by enhanced SOM) reduces air borne particulate matter, it also prevents the loss of SOC.

3.4.2. Activity 3.2. Identifying environmental trade-off data

The literature review identified a significant number of scientific publications, research reports and databases and a variety of other sources of environmental trade-off information. The majority of this is qualitative rather than quantitative and work has been undertaken to capture this in a format that can be used by the 'tentative' model.

The format of the data needs to be common to all impact categories in order for it to be stored and used within the core database that underpins the 'tentative' model. The format and fields that currently exist for this information include those listed and described in Table 3.4.6. The fundamental work in this area is complete but it is being revised and polished as the 'tentative' model develops further.

Table 3.4.6: Data structure for other impacts

Field	Description
Impact category	This is the main impact area and is drawn from a common set of impact categories, for example: air quality, biodiversity, countryside access and recreation, efficient use of resources, energy, landscape and heritage, soil quality, waste and recycling, and water quality. At this moment this is a single impact category, however a hierarchy may be developed in order to allow for more specific impacts, for example a specific impact category of 'maintain/improve physical soil status' within the impact group of 'soil quality'.
Positive or Negative	This determines whether the effect (of the mitigation option/practice) is a benefit or burden with respect to the impact category.
Impact Score	This will be used to reflect the significance of the impact. A number of scoring systems are being examined and tested. For example, on a very simple basis, 1 would be low or negligible, 5 would be moderate and 10 would be a highly significant impact.
Unit	This determines the unit basis of the impact, e.g. it could be per hectare, per farm, or per tonne, depending on the mitigation option.
Quality	This is used to note the quality of the evidence on which the impact has been based.
References	The reference sources of the evidence supporting the impact.
Notes	Other pertinent information relating to the impact and/or the evidence.
Modifiers	The factors that may influence the significance of the impact, e.g. soil type or any environmental designations.

Tables 3.4.7, 3.4.8a and 3.4.8b provide some examples to illustrate how this information is being captured.

Table 3.4.7: Other impacts of converting cultivated land to improved grassland

Field	Description
Impact category	Soil quality: Maintain/improve physical soil status
Positive or Negative	Positive
Impact Score	5
Unit	Per hectare
Quality	-
References	Cuttle, S.P., C.J.A. Macleod, D.R. Chadwick, D. Scholefield, P.M. Haygarth, P. Newell-Price, D. Harris, M.A. Shepherd, B.J. Chambers, and R. Humphrey. (2007) *An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA): User manual ES0203*. Defra, London
Notes	Soil structure can be improved under grass.
Modifiers	Impact may vary with soil type

Table 3.4.8a: Other impacts arising from avoiding the use of sub-soiling (soil quality)

Field	Description
Impact category	Soil quality: Maintain/improve physical soil status
Positive or Negative	Negative
Impact Score	2
Unit	Per hectare
Quality	-
References	Chamen, W. C. T., Alakukku, L., Jorge, R., Pires, S., Sommer, C., Spoor, G., Tijink, F., Weisskopf, P., van der Linden, P. (2000) *Equipment selection and field practices for the control of subsoil compaction-Working Group methodologies and data acquisition*. In: Proceedings of the Third Workshop of the Concerted Action on Subsoil Compaction, Uppsala, Sweden, June 14-16, 2000. Report 100. Department of Soil Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden, pp. 207-219. Chamen, W. C. T., Alakukku, L., Pires, S., Sommer, C., Spoor, G., Tijink, F., Weisskopf, P. (2003) Prevention strategies for field traffic-induced subsoil compaction. Part 2. Equipment and field practices. *Soil Tillage Research*, **73**, 161-174
Notes	Not sub-soiling may lead to less infiltration and more run-off and erosion.
Modifiers	Impact may vary with soil type

Table 3.4.8b: Other impacts arising from avoiding the use of sub-soiling (landscape and heritage)

Field	Description
Impact category	Landscape and heritage: Protection of archaeological sites and features
Positive or Negative	Positive
Impact Score	8
Unit	Per hectare
Quality	-
References	Wildesen, L. E. (1982) *The study of impacts on archaeological sites, Advances in archaeological method and theory*. ISBN 012-003105-1 Olson, G.W. (1981) Archaeology: Lessons on future soil use. *Journal of Soil and Water Conservation*, **36(5)**, 261-264
Notes	Not sub-soiling avoids deep soil disturbance and consequently helps protect any underlying archaeology
Modifiers	The presence of any archaeological features (e.g. no features score = 0, some features score = 5, scheduled or designated feature score = 8)

The process of identifying some of the impacts and trade-offs has utilised a database (known as the Activity-Effect-Outcome (AEO) database) recently developed in the UK (Tzilivakis *et al*., 2009; Tzilivakis *et al*., *Submitted*) to help identify potential environmental benefits and burdens of agricultural activities. The AEO database stores all the 'top-down' effects/impacts for specific agricultural activities and vice versa all the 'bottom-up' causes of outcomes/impacts. In so doing it provides a 'map' of the effect-chains (including intermediate processes) and allows the creation of an activity-outcome matrix, thus aiding the identification of all the potential negative and positive (and so trade-offs) impacts associated with agricultural activities, including some climate change mitigation options. The AEO database also stores relevant reference sources for each link in the effect chains. The AEO database is being interrogated using the mitigation options that are in the core IMPACCT database (see Section 3.5.2, Task 4.2) and the results of these interrogations are being used to help populate the 'other impact data' core database.

The process of extracting data and information from the literature review and formatting it into the database is well underway. However, it is envisaged that population of the core database with data on other impacts will be ongoing throughout the life of the project to keep the database up to date.

The Impact Scores (see Tables 3.4.6 to 3.4.8) for other impacts have been adjusted based on a number of modifying variables, and these variations in the scores are stored in the core database. As such the Impact Score that is calculated for a farm is tailored to the specific circumstances for the farm. For example, those activities that have an impact on biodiversity (positively or negatively) have a higher score if the farm is within a Special Protection Area (SPA) or Special Area of Conservation (SAC).

Within the software, where other impacts are identified they are currently flagged up using a red triangle ( ) and green circle ( ) to express potential negative and positive impacts respectively. The score for the other impact is currently presented alongside these graphics and text. We are currently examining options to see how this score could also be converted to a graphic, so that interpretation is more visual.

To aid interpretation, rather than present the graphics above and a score and the name of the impact category, statements have been developed to be used instead to convey the impact. For example, rather than display Maintain and enhance biodiversity: Birds - improve habitat and management (-40), the software will display Potential damage to bird populations (-40), or if the impact is positive Potential benefit for birds (+40).

3.5. Task 4: Integrated Whole Farm Assessment

Activity Start Date	M1	Activity Finish Date	M10
Milestones and Deliverables	'Tentative' model		
Key project partners involved	University of Hertfordshire		

The objective of Task 4 was to develop a framework that combines the outputs of Tasks 1 to 3 into a model for integrated whole farm assessment (IWFA). The focus of the task was on the development of a robust data model/structure that is capable of storing and providing data and information to aid decision making at both the policy and farm level.

The work undertaken included the development of a software interface that gathers data from the user and utilises this data to interrogate the database developed to format and store the data collated in Tasks 1 to 3. Routines were developed to calculate an emissions inventory for the described farm and report these back to the end user together with mitigation options, financial implications and information on any identified environmental benefits or burdens.

3.5.1. Activity 4.1. Requirements definition

The purpose of this part of Task 4 was to develop a detailed specification (a 'blueprint') of the model to be developed. A number of key requirements were outlined in the tender specification document. The main objective of this Activity was to build upon these via the national consultation exercises and feedback from potential end users.

3.5.1.1. The Farm Level

A questionnaire was given to farmers taking part in the case studies which consisted of a number of multiple choice type questions relating to design, functionality and outputs. It also included space to add comments and additional suggestions. The results were then collated together in a spreadsheet so that the consensus could be identified. This is summarised below:

- Simplicity of use and free of charge were a common requirement;
- Concerns over the input data requirements were frequently expressed either due to the time required to gather and/or input the data or due to an absence of such data. Many farmers interviewed said that input data should be kept to a minimum, default values should be available and that any data required should be easy and cheap to obtain;
- Provision of integrated help-text, user support and training was frequently requested;
- The use of techniques that minimised typing, such as menus, drop down list and tick would be preferred;
- The system should be transparent regarding the data used and the calculation methods;
- The 'tentative' model should be able to calculate the key emissions and sinks. It should also provide a site or enterprise carbon balance and advise on appropriate, site specific mitigation options;
- The system should also account for off-site benefits as an optional extra;
- Outputs in terms of the way they are displayed (data, summaries, graphics etc.) and how the data is expressed (per area, enterprise or economic unit) should be flexible and customisable;

- The system should be able to explore what-if scenarios, enable annual comparisons and benchmarking;
- The 'tentative' model should be able to provide guidance on the quality of the results in terms of data quality, missing data and reliability;
- Several farmers requested that it should be translated into their native language to encourage wider use. This was a particular requirement where English is not widely spoken amongst farmers e.g. Hungary, Poland and Slovenia.

Of the options provided, those given the least priority included:

- Providing results by economic unit;
- Displaying results using a non-numeric or relative format (e.g. high/medium/low, colour coding etc.).

These requirements and those described in the EC project tender formed the basic 'blueprint' for the farm level tool. The key requirements are shown in Box 1 below.

Box 1 - The Farm Level Tool

- Identify/calculate the key sources of greenhouse gas emissions on an individual farm
- The ability to monitor mitigation actions at the farm level on a temporal basis
- Identify/calculate the key sinks (carbon sequestration) on an individual farm
- Identify/calculate the carbon balance (sinks – sources) for the farm
- Identify mitigation options relevant to a specific farm to reduce emissions
- Identify mitigation options relevant to a specific farm to increase carbon sequestration
- Assess the economic cost of any mitigation options that might be identified
- Identify any potential environmental impacts of mitigation options i.e. environmental trade-offs
- Direct users to relevant sources of further information and advice
- Provide both graphical and numerical outputs such that end users can select and customise outputs to suit their own needs
- Print results
- Save input and results data such that it can be recalled and re-used
- Explore what-if-scenarios on any one farm
- Compare results from year to year (for the same farm)
- Benchmark (e.g. compare to similar farms)
- Express results per tonne of output, per economic unit, per farm, per area (e.g. ha) and per annum

3.5.1.2. The Policy Level

The basic requirements of a tool for policy makers were given in the project tender document. However, Part 2 of the Member State consultation exercise (see also Task 2.2 in Section 3.3.2) sought to build on this and identify any additional or different priorities and desirable facilities and features. The feedback is summarised below in Table 3.5.1.

Table 3.5.1: Requirements for Policy Application

Member State	Key points for policy application
United Kingdom	• Should be free of charge, comprehensive and easy to use; • Should be reactive to changes in farm practices and site specific parameters; • Should provide outputs in a variety of formats and customisable – data, graphics, summaries, etc.; • Should differentiate between permanent and temporary emissions.
France	• Should be able to calculate emissions by enterprise as well as farm totals; • Should include a guide to economic data; • Should be able to explore what-if scenarios; • Should be able to use existing datasets; • Flexibility in the type of outputs would be useful.
Germany	• Should be comprehensive, versatile and flexible; • Should be able to use existing datasets; • Should provide outputs in a variety of different formats – data, graphical, summaries etc.; • Should be able to describe results in a variety of different ways e.g. on a yield or production area basis.
Italy	• Should cover all relevant emission sources; • Should provide details of mitigation actions; • Should include a guide to economic data; • Should be able to use existing datasets; • Should be flexible in terms of outputs and results presentation.
Poland	• Should be flexible in terms of outputs; • Should be simple to use; • Should be translated into different languages; • Training and support should be provided; • Should be free of charge.
Slovenia	• Should be simple; • Should not be demanding with respect to input data; • Training and support should be provided.
Hungary	• Should not be demanding with respect to input data as statistical data limited in availability; • Need to obtain a balance between tackling the issue adequately and still keeping it relatively simple to use.

These requirements and those described in the EC project tender formed the basic 'blueprint' for the policy level tool. The key requirements are shown in Box2 below.

Box 2 - The Policy Level Tool

- Search for greenhouse gas emissions/carbon sequestration data by farm type
- Search for greenhouse gas emissions/carbon sequestration data by region or member state
- Search for greenhouse gas emissions data/carbon sequestration for specific agricultural activities
- (Combinations of the above)
- Display economic data attached to mitigation options
- Identify any potential environmental impacts of mitigation options
- Combine outputs with geo-spatial data
- View outputs temporally, e.g. plot trends over time
- Explore what if scenarios, e.g. using specific farms
- Use existing datasets
- Override emissions factors with your own data / use alternative factors

3.5.2. Activity 4.2. Core database – design and construction

This project has developed two databases. The first is known as the 'primary Knowledge Base' and has been designed and constructed to handle the large amount of data collated during the study. The second database is known as the Core Database and this supports the 'tentative' model. The Core Database is created from the primary Knowledge Base using a data export facility. This database only includes data necessary for the operation of the tools. The Core Database stores a range of data including:

- Farm Enterprises and Typology
- Enterprise components and structure
- Modifying variables for components
- Relevant data for each sub-component including emissions of GHGs, sequestration, economics, other impacts and energy use
- Central repositories for the Units used for each data item and Reference sources of the data

A more detailed description of the data held is given below and Figure 3.5.1 shows the structure of the Core Database.

Farm Enterprises and Typology: The farm typology (see Section 3.2.1, Activity 1.1) has been captured within the database. This includes Enterprise (EID); General Type (GT); Principal Type (PrT); Particular Type (PaT); and Sub-groups (SG). Currently the EID is the main part of the typology that is being used in relation to data storage. EID's have also been mapped (see Table 3.2.2) against GT, PrT, PaT and SG so that the data stored within the database can be cross referenced with any other data that has been collected using the EU farm typology. Each EID is mapped against relevant components.

Enterprise components and structure: Each enterprise is broken down into components (see Section 3.2.2, Activity 1.2). These components consist of primary and sub-components (secondary). Data are stored against each sub-component with variations in data stored using modifying variables.

Modifying variables: These allow variations in data, e.g. different emissions from different mitigation options, to be stored for each enterprise component. They consist of a list of Modifiers and the Classes within each modifier.

Data: The following data for each component can be stored: emissions of greenhouse gases; sequestration of carbon; economic data; data on other environmental impacts and energy use. Each of these is stored in a separate table within the database, with relevant fields for the appropriate data. Where there are modifying variables, the combinations of modifiers and modifier classes used are stored in a separate table for each of the data tables. They are also stored as a composite data item in a single field with the data table, but for the moment they are stored in two places to allow flexibility when interrogating the database. This may change in the future once the tools have been developed and their interrogation requirements are better defined.

Central repositories: There are current two central repositories within the database. Firstly, the Units that are used to store the data (e.g. per hectare, per tonne, etc.) are all defined in a single table. These can then be used when populating and interrogating the database. Secondly, the reference sources for each data item in the database are all stored centrally – thus when the database is being populated the reference sources can be 'picked from a list' rather than re-entered each time.

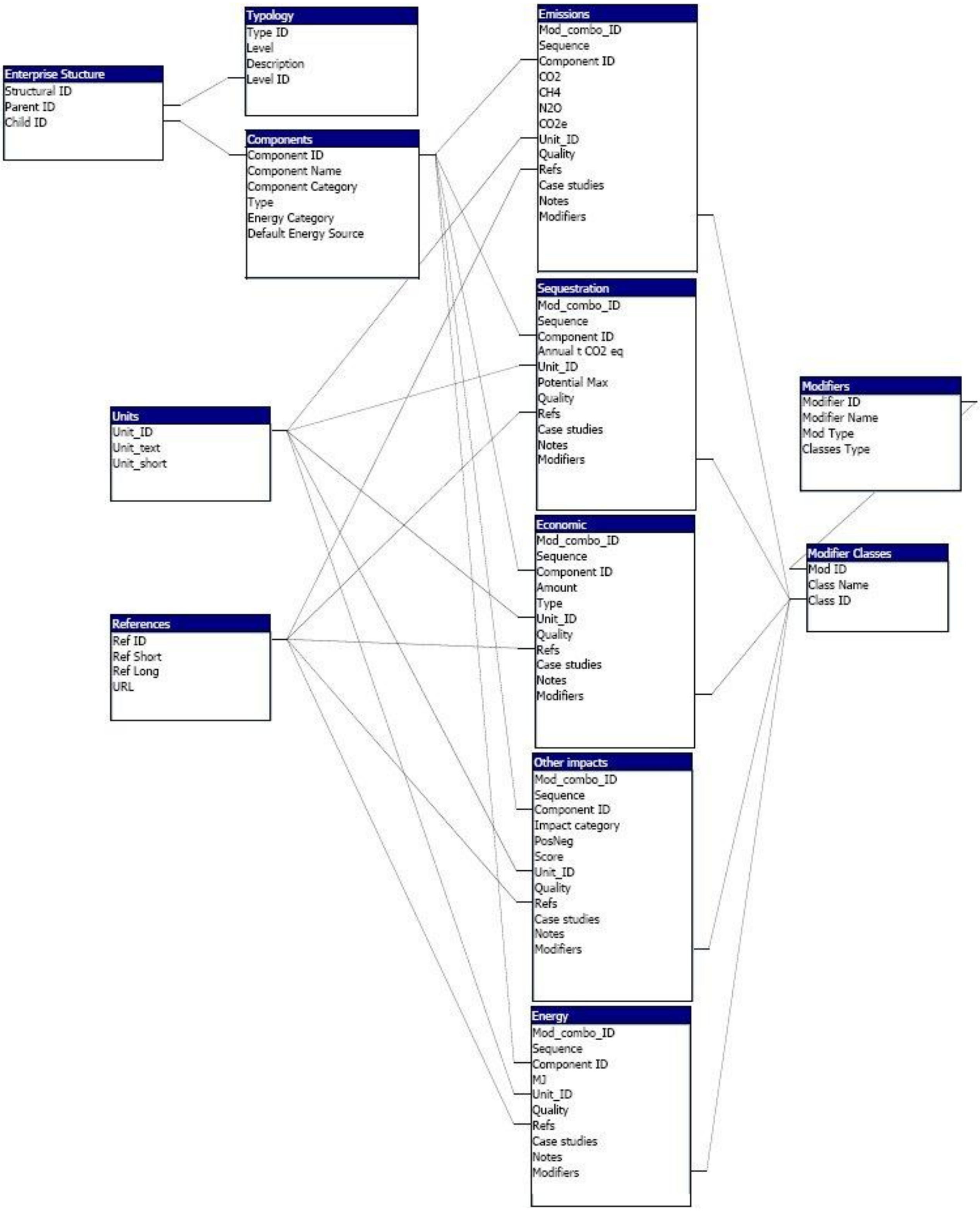


Figure 3.5.1: Database structure (MS Access Relationships view)

In addition to those shown in Figure 3.5.1, there are number of additional tables that store information required by the model. These include:

- **Calculations:** The core database stores details of all the calculations that need to be undertaken to calculate emissions, sequestration, economic and other impacts for a farm. Storing them in the database allows the calculations to be centrally managed allowing easier and more rapid updating.
- **Component Energy:** This table stores information about what energy sources can be used with which components and which source is the default energy source. This table prevents users from selecting energy/fuel sources that are not applicable for certain activities (e.g. mains electricity for ploughing) and also auto-selects the most likely fuel source when the user creates their farm assessment, e.g. diesel oil for field operations.
- **Component Structure:** This provides a 'parent-child' structure to the components to allow data to be easily aggregated. For example, the parent component ' Seedbed preparation' will have Ploughing, Subsoiling and Harrowing as child components. Thus it is possible to display data for each of the 'children' or aggregate it to present a single figure for seedbed preparation.
- **Data Items:** This table stores details about all the data that may be requested from the user in order to undertake the calculations for their farm. Each data item has a unique ID and is linked to the Calculations table (see above) and also to specific components (see Data-Comp Links below).
- **Data-Comp Links:** This table stores details of the links between components and data items. When a user selects a component for their farm and relevant data items are then identified. This is used, for example, to prompt the user to enter outputs from farm enterprises (e.g. tonnes of wheat) and is also used to identify which components contribute to those outputs, thus allowing the software to allocate emissions to specific outputs in order to calculate emission per output (e.g. X tCO_2e per tonne of wheat).
- **Impact Categories:** This table stores a complete list of other impact categories. It also stores phrases for each impact category to be displayed to express statements of positive or negative impact.

Software to manage and populate this knowledge base has also been developed and this is shown below using a number of screenshots. Figure 3.5.2 provides an illustration of a tree structure within the management software that shows a list of enterprises, their primary components, sub-components, modifiers and modifier classes. This demonstrates how the data that are held in the database are brought together into a logical structure.

Figure 3.5.2 shows how the Enterprise Cereals has a number of components, including Seedbed preparation. This component then has a set of sub-components, including Ploughing. The data for ploughing (in this instance energy use) will vary according to the ploughing depth and the soil type, so these are both modifiers. In the case of ploughing depth there is data available for 15, 20 and 25 cm depths (and for each soil type). Figure 3.5.3 shows the data that are in the database for this example, with different combinations of soil type and depth.

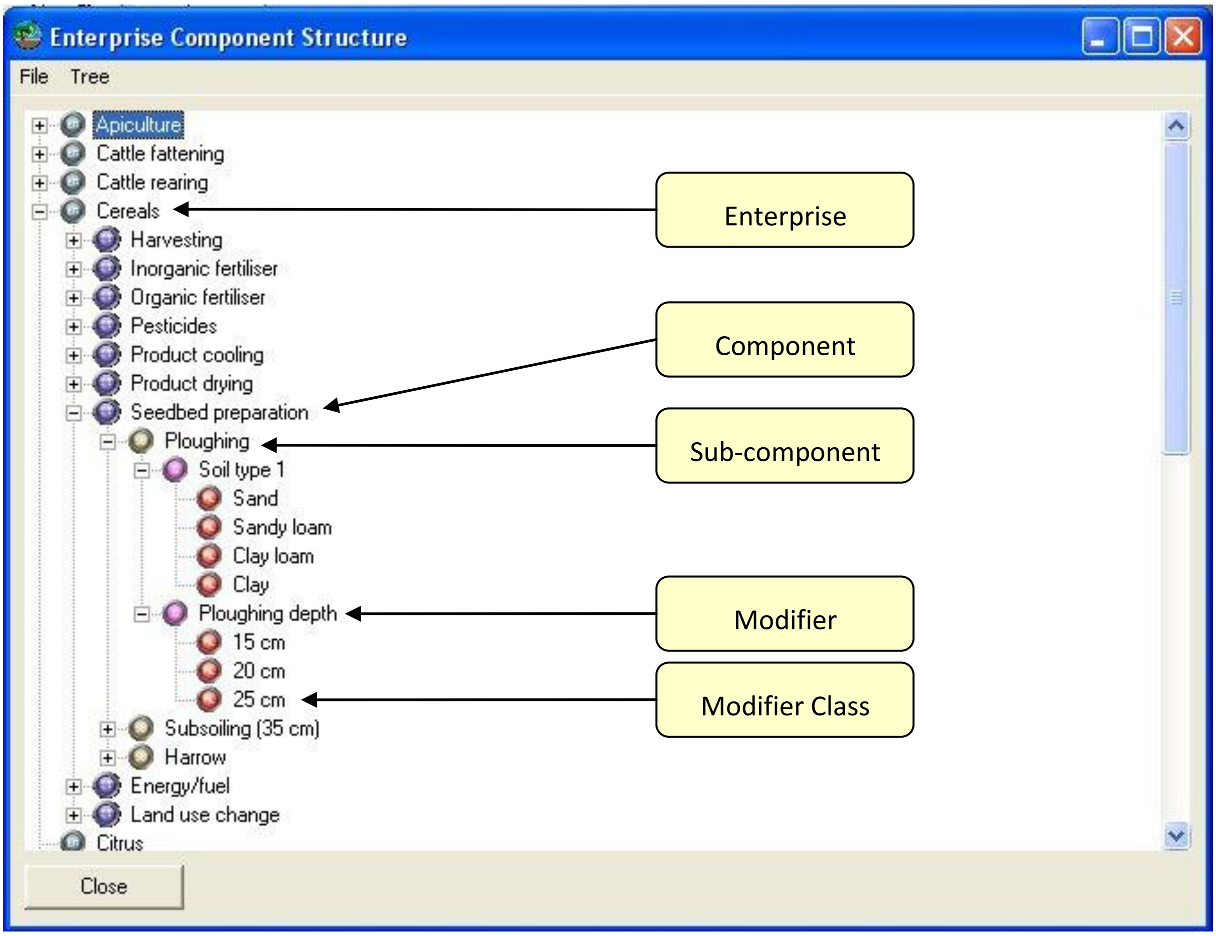


Figure 3.5.2: Tree structure to view the structure of enterprises, components and modifiers

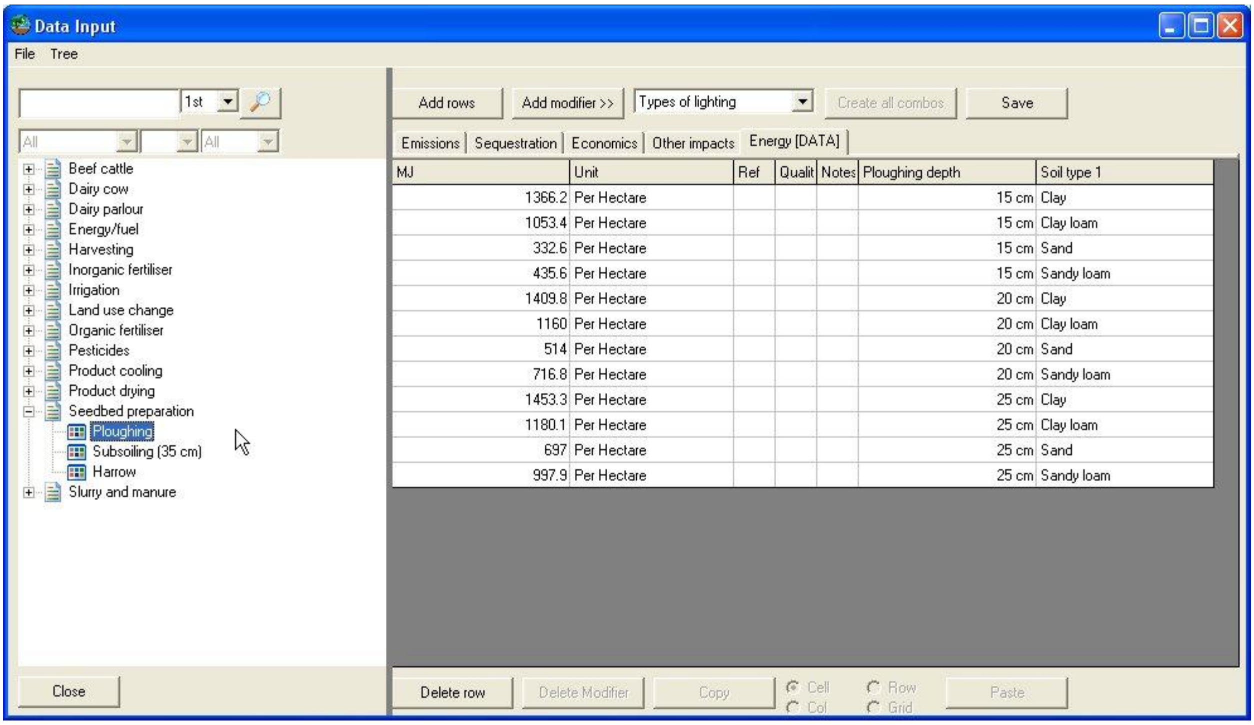


Figure 3.5.3: Energy data for ploughing

Each data item in the database can have notes and references sources stored alongside it. Figure 3.5.4 shows another example of data, this time for losses of nitrous oxide from deposition excreta on pasture from a 650kg dairy cow.

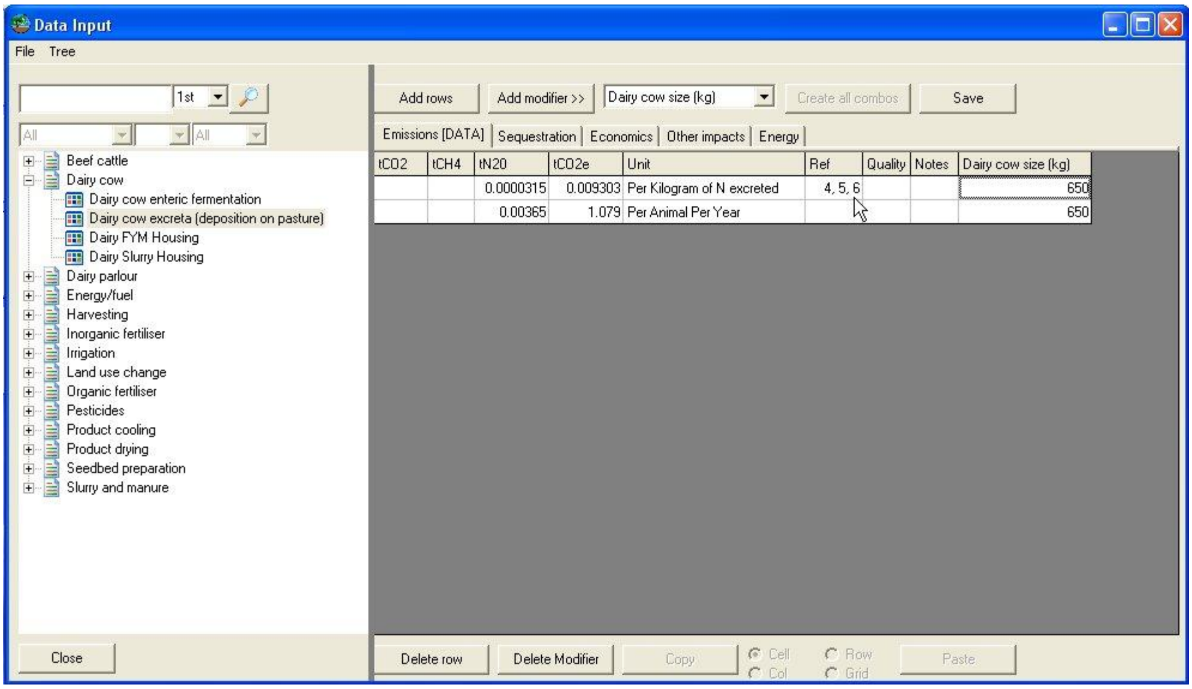


Figure 3.5.4: Emissions data for dairy cow

In Figure 3.5.4 the 'Refs' column contains several numbers. These refer to specific sources that are held centrally within the database, clicking on the cell will display those sources (and allows others to be added), as shown in Figure 3.5.5.

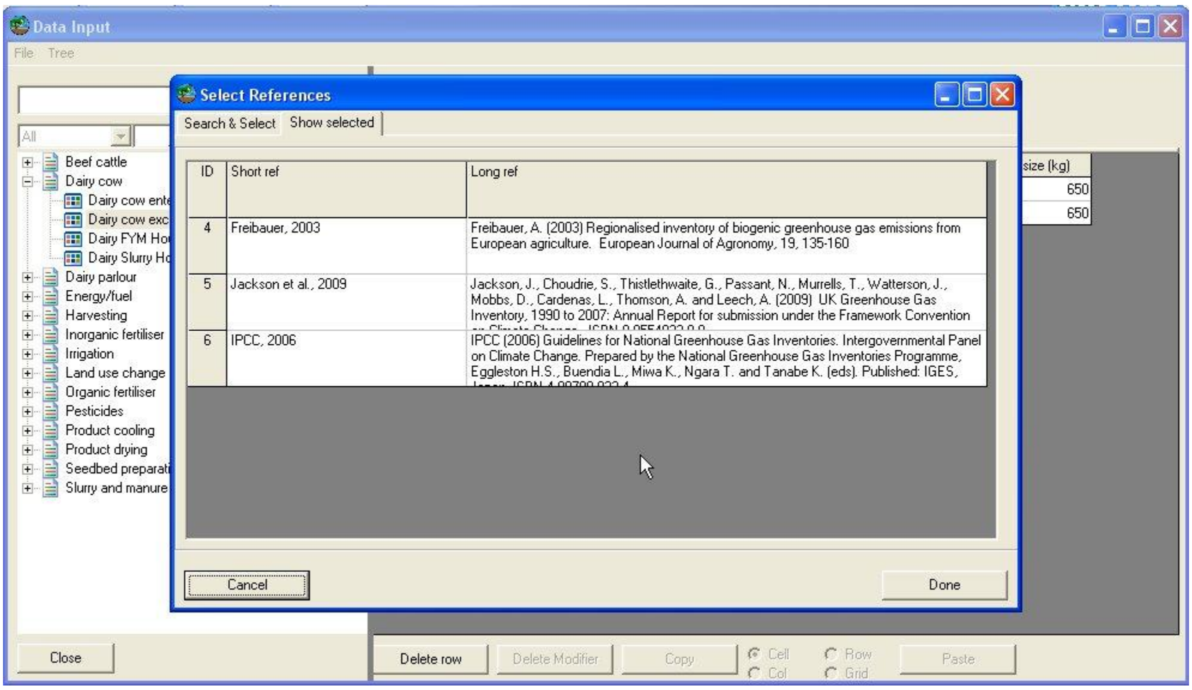


Figure 3.5.5: Reference sources for data

3.5.3. Activity 4.3. Core database – population: knowledge base processing

During the study work has been undertaken to extract data and information collated during the literature and knowledge review, to format this information and then populate the 'primary knowledge base' ultimately creating the Core Database.

In many respects the approach to populating the core database is similar to a meta-modelling approach, whereby data on emissions and sequestration are structured according to a number of fixed and variable factors (modifiers). Thus rather than have a complex mathematical model of emissions, specific emission factors are stored in a 'look-up' table and these factors have often been derived from other, more complex, mathematical models. Therefore, a user does not need to run any complex scientific models for their farm, they need only select the components and variables and then the software will look up the appropriate data and calculate the emissions and sequestration profile plus all the potential mitigation options for their farm. Whilst this may slightly decrease the accuracy of the 'tentative' model regarding the carbon balance, it is unlikely to effect the identification of appropriate mitigation options. It also offers a wide range of advantages. Firstly the 'tentative' model can remain relatively simple, should be quick to run and can cover a broad and comprehensive range of farm activities. Scientific models are often narrow in their application (i.e. do not adopt an integrated approach) and are not likely to be used by farmers due to their complexity, input data requirements and the outputs data format.

The population of the database is also driven, to some extent, by the farm component structure. In order to meet the requirements of the model, the farm component structure used within the software has also been used to structure data within the core database. In some instances this means that data are structured by crop and for some sub-components data is duplicated. In order to avoid any discrepancies arising, where data are duplicated for reasons of component structure, the data items are linked between components so that updating the data for components will update the same data for all linked components. For example, the energy used for pesticide production is the same regardless of crop, but in the database there are pesticide production components for each crop (so that it is possible to calculate and allocate the energy used to produce the pesticide used on each crop). Rather than enter or update the data for pesticide production for each crop component, it needs only to be done for pesticide production component and all the others will be updated.

In order to speed up the process of database population (and also to aid future updating) an Excel export and import facility for the core database has been developed. This allows the data structure for a component to be exported and opened within Excel. In some instances where there are large number of variables, and a large number of combinations for which data needs to entered, it is easier to do this within Excel due to its superior layout and copy and paste functions.

3.5.4. Activity 4.4. Mechanisms for dealing with gaps in data, knowledge and data quality

Relevant data, identified in the literature, is of variable quality. Whilst we have endeavoured to select the best available, inevitably some will be better than others and compromises have had to be made. There will also be situations where there may be gaps in data. It is therefore essential that information relating to data quality and missing information are conveyed to the end user together with some interpretation regarding the impact of these on the final results. Therefore a 'quality barometer' has been developed (Lewis *et al*., 2007; Lewis *et al*., 2003).

Each item of data in the core database has a corresponding field to hold a data quality score. This score ranges from 0 to 5, where 1 is low and 5 is high. The score is awarded using expert judgement and based on the quality of the evidence supporting the data as shown in Table 3.5.2. For example, 5 would be well established data supported by numerous empirical studies, whereas 1 might be anecdotal information or single one off studies that have not been replicated. Other areas where uncertainty may exist may shift the barometer down further. For example if data is from a respected source (i.e. a quality score of 4 or 5) but there are still doubts about the data set due to, say, monitoring issues then the barometer score might be reduce further (i.e. to a 3 or 4). As such this score becomes a surrogate indicator for the degree uncertainty attached to the data.

Table 3.5.2: Rules for assigning data quality scores needs

Quality Value	Guideline
4 or 5	▪ there is ample, well documented evidence in peer reviewed scientific and/or best practice literature supporting the data; ▪ data are useable in its published format; ▪ data are from a recognised and respected source such as a government department.
3 or 4	▪ there is some documented evidence in peer reviewed scientific and/or best practice literature supporting the data; ▪ data has been generated using well recognised and accepted mathematical models (meta-modelling approach); ▪ whilst the data is high quality, it requires some conversion or adjustment before it can be used in the model.
2 or 3	▪ there is limited documented evidence in support of the data; ▪ models used to generate the data are not widely used or recognised as having limitations; ▪ data source is not well known.
1 or 0	▪ anecdotal evidence; ▪ expert judgement; ▪ unknown or unverified source.

When a data item is retrieved from the database it's data quality score is also retrieved. Then for each calculation the data quality scores for the data used in that calculation are summed and then averaged, to give an overall data quality score the output of the calculation. Where data are aggregated, e.g. when combining emissions for child components to display a figure for the parent component, the data quality scores for each number are summed and averaged again.

Actual data quality scores are not displayed to the end user. Instead a data quality graphic (see Figure 3.5.6) is used (similar to the signal strength indicator used on some mobile phones or wireless networks) to reflect the relative 'strength/quality' of the data and thus the level of uncertainty in any results.

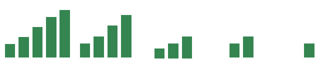


Figure 3.5.6: Data quality indicator graphics (high to low)

It should be noted that the data quality score is a reflection of the attributes of the source of the data and does not necessarily represent the uncertainty. Some aspects, such as carbon sequestration, are currently inherently uncertain and a range of values can exist for certain parameters. This is not necessarily totally reflected in the data quality score. It will have been taken into account, but what should be done would be to include the range of data (e.g. from best to worse case) and store this within the core database and then allow the model to draw upon these figures to express a range within the end results.

3.5.5. Activity 4.5. Calculations and data handling within the model

There are a number of key processes within the software that undertake the calculations and data handling. These include:

- Calculation of emissions, sequestration, economic and other impacts;
- Processing of data to present results to the user and identify potential mitigation options;
- Data storage (saving and opening data).

As described above (Section 3.5.2) all the calculations for calculating emissions, sequestration, economic and other impacts are stored within the core database. Therefore to calculate these for a farm the user simply selects their enterprises, farm components, energy sources, modifying variables and any quantities involved (e.g. amounts of fertiliser used, area of crops, tonnes of output, etc.). The software then retrieves the relevant calculations from the core database and then for each component calculates emissions, sequestration, economic and other impacts. In many respects this is a relatively straightforward process (albeit with a lot of complicated computer coding underneath). The next step is to compile and present the results in a format to aid the user with respect to understanding the emissions and sequestration profile of their farm and to help identify potential mitigation options.

The parent-child structure (see Section 3.5.2) of farm components means that it is possible to aggregate the results from the calculations into a shorter list of components or activity areas for the farm. This highlights the most significant areas of the farm with respect to their contribution to emissions and sequestration and any other impacts. In order to be able to determine potential mitigation options the software needs to calculate emissions, sequestration, economic and other impacts for all the other potential combinations on the farm. These combinations are determined by the modifying factors that are relevant for each component. Some of these are fixed (e.g. soil type or climate) and some are variable (e.g. choice of equipment or specific practices). The software examines the variable modifiers selected and then generates all possible combinations of the classes within these modifiers for each component. In some instances this can lead to several hundred combinations for a single component. Then for each combination for each component the emissions, sequestration, economic and other impacts are calculated. Each combination for each component can then be compared to the result for the current farm and thus the potential for mitigation can be calculated both against the emissions for that component and the farm as a whole (expressed as a percentage).

The calculation results for economic and other impacts are presented alongside each potential mitigation option, so that the user can take this information into account. For example, an option that could have the greatest potential to reduce emissions on a farm, may also have economic and other impacts, so the user needs to be made aware of this.

In some instances a variable modifier may affect emissions, sequestration, economic and other impacts in more than one component. For example, livestock diet will affect emissions from the animal itself, e.g. via enteric fermentation, and may also impact upon emissions from the storage and application of the resulting manure from that animal. It is important therefore to take a holistic view and understand the net benefit of any specific modifier. To address this, the software processes the results of the mitigation calculations to examine and identify the mitigation potential of specific modifiers. For example, rather than looking to just mitigate livestock enteric fermentation on its own and/or emissions from manures on their own, the software will identify where changing the diet X will reduce emissions from both enteric fermentation and manures – thus providing the user with the net benefit of that option. This is an important function as potentially there could be situations where there are trade-offs and/or synergies to consider. For example, the results may show that changing to diet X will reduce emissions from enteric fermentation but it could be that changing to diet X may increase emissions in another farm component – thus it is the net balance that is important.

Finally, all of the above information that the user enters and is consequently generated must be stored. Input data is stored within a database file (the file extension '.imd' is used in association with the IMPACCT software) along with the basic results. Data can later be retrieved, edited and printed if required and the file can be transferred, moved and copied like any other computer file.

3.5.6. Activity 4.6. Development of the user interface

A key design consideration for the software is to keep the user interface as simple as possible in order to simplify its use and maximise its uptake by end users. There is no doubt that the current interface could be improved in this respect, but given the time that was available to develop the tool and that it is a 'tentative' prototype model the current interface is considered to be acceptable and has the scope to be improved based on feedback from users during the Phase 2ii case studies.

The purpose of the user interface is to provide:

- An introduction and welcome to the software;
- A means of navigation;
- Facilities for data input and editing (for creating a farm assessment);
- Screens to display results;
- Facilities that provide help, support and updates.

3.5.6.1. Introduction and welcome to the software

Upon starting the software the user is presented with what has been termed the 'front/navigation' screen. This screen performs a number of functions but principally acts as a central hub from which to access all the tools, functions and services within the software (see Navigation below). It also provides a central area for displaying text. When the software is first opened the central part of the screen will display some welcome and introductory text. This will include information on how to get started for first time users.

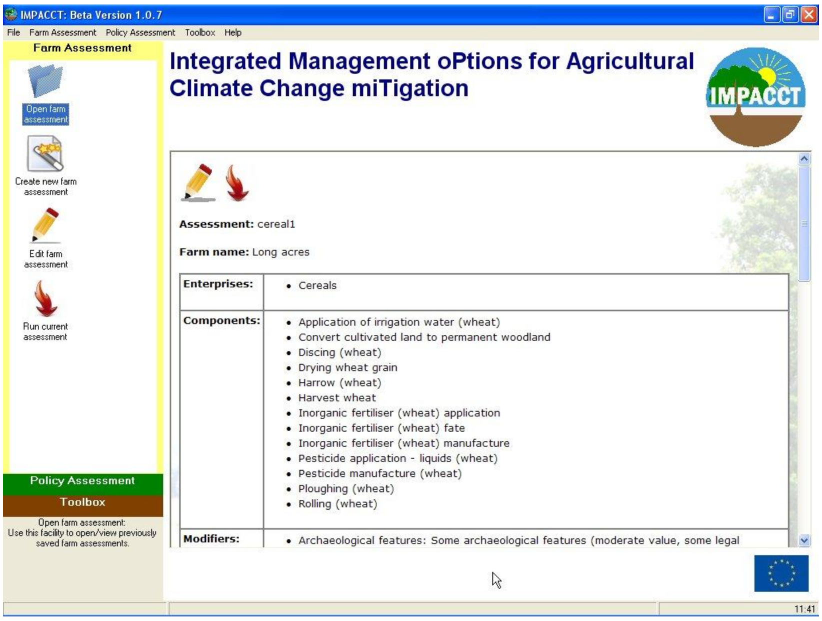


Figure 3.5.7: Front/navigation screen – farm assessment data

The central text area also serves an additional function of displaying the name and details of the farm assessment file that is open at that time. So when a user opens an IMPACCT farm assessment file, the data that has been entered for that farm is summarised and displayed (see Figure 3.5.7 for an example).

3.5.6.2. Navigation

Figure 3.5.7 shows the main elements on the front/navigation screen. At the top there are a number of menu items, down the left side there is an 'Outlook' style navigation bar and in the centre of the screen is the text display area (as previously described above). The functions of the Farm Assessment, Database and Tools menus at the top are duplicated using bigger icons within the 'Outlook' style bar giving the user a choice of navigation routes. However, the icons displayed on the left hand side of the Welcome screen provide the main means of navigation through the software and provide a number of facilities:

- Farm Assessment:
  - Open farm assessment – allows the user to manage and open previously saved farm assessments;
  - Create new farm assessment – initiates the Farm Assessment Wizard with a new (blank) farm assessment;
  - Edit farm assessment – initiates the Farm Assessment Wizard populated with data from the farm assessment file that is currently open;
  - Run current assessment – initiates the calculation routine for a farm assessment that is currently open and then displays the results.
- Policy Assessment:
  - IMPACCT Policy Project – a facility to create new or open existing policy assessment projects (e.g. as used in Task 5 for policy opportunities analysis)

- Toolbox:
    - Settings – allows the user to adjust some of the software settings and also check for software updates;
    - Database Search – allows users to search the underlying core database in the software to view the emission factors (and other data) used within the software.
    - Other tools and help facilities will also be added in as identified by the piloting and case study exercises.

3.5.6.3. Opening a farm assessment

Selecting 'Open farm assessment' will display a facility to view, compare, open, edit and run previous created assessments (see Figure 3.5.8). This enables the user to manage their previous assessments. For example, a user may wish to create several variations for their farm, with different mitigation options selected and then compare the results of each assessment side by side. Alternatively, a farm consultant may use the software for several farms creating a different assessment file for each farms, and this facility allows them to manage these different files, for example being able to search and sort by farm name.

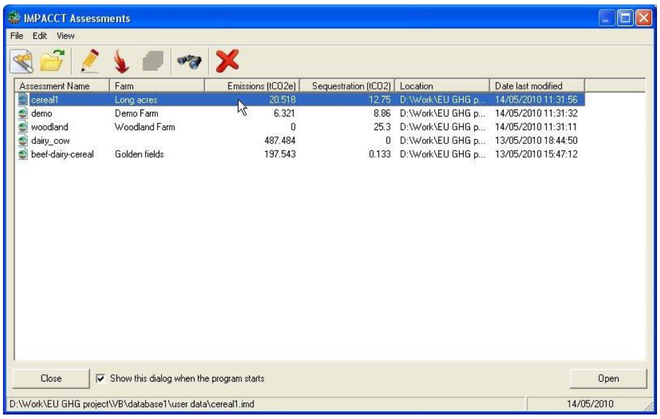


Figure 3.5.8: Open Farm Assessment screen

3.5.6.4. Data input and editing – the Farm Assessment Wizard

Clicking on 'Create new farm assessment' or 'Edit farm assessment' will launch the Farm Assessment Wizard (the latter with data that is currently open, the former will create a blank farm assessment). The wizard is a core part of the software that allows the user to construct, edit and run farm assessments. The wizard breaks the process of constructing a farm assessment into a number of steps:

1. Selecting farm enterprises
2. Selecting farm components
3. Selecting energy sources for components
4. Selecting modifying variables for components
5. Entering data on quantities
6. Selecting options that affect what mitigation options are determined

Each of these steps is described in detail below. At any point during the wizard steps the user can save their data like any other computer file using the Save option on the File menu.

The first task is to select one or more farm enterprises. This simply a case ticking boxes on a list of enterprises.

After selecting enterprises the user is presented with a list of farm components. These are structured using the parent-child structure for components in the core database. The user simply selects the components that are relevant to their farm (see Figure 3.5.9). In some instances components are automatically selected, e.g. if a user selects 'pesticide application – liquids', the component 'pesticide production' is automatically selected (using the logic that if pesticides are being applied, then they are also being produced).

The next step in the wizard is to select the modifying variables for the farm (based on the enterprises and components selected in the previous steps). This is done in similar fashion to the selection of components - except a selection must be made under each modifier in order for the user to proceed (the software will prevent the user from proceeding until a selection has been made). In some instances single modifier classes need to be selected (marked with the S icon) and other instances multiple selections can be made (marked with an M icon) (see Figure 3.5.10).

Once the modifying variables have been selected the user can enter data on quantities. This involves typing in the amounts for the various items listed using the units shown (see Figure 3.5.11). This data is then used in the calculations to determine emissions, sequestration, economic and other impacts.

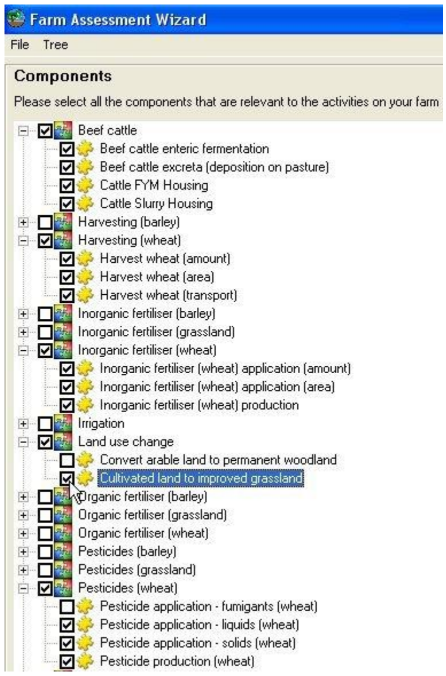


Figure 3.5.9: Farm Assessment Wizard: Selecting farm components

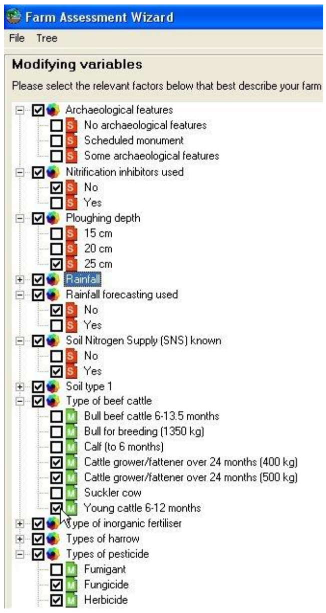
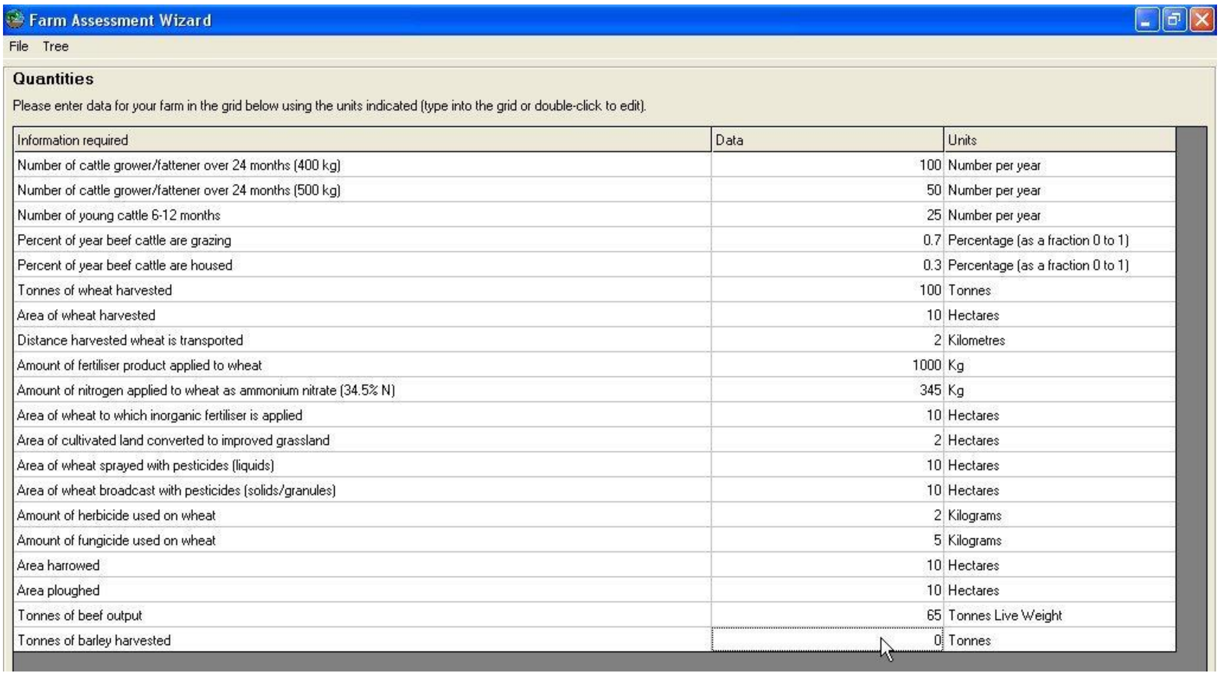


Figure 3.5.10: Farm Assessment Wizard: Selecting modifying variables



Information required	Data	Units
Number of cattle grower/fattener over 24 months (400 kg)	100	Number per year
Number of cattle grower/fattener over 24 months (500 kg)	50	Number per year
Number of young cattle 6-12 months	25	Number per year
Percent of year beef cattle are grazing	0.7	Percentage (as a fraction 0 to 1)
Percent of year beef cattle are housed	0.3	Percentage (as a fraction 0 to 1)
Tonnes of wheat harvested	100	Tonnes
Area of wheat harvested	10	Hectares
Distance harvested wheat is transported	2	Kilometres
Amount of fertiliser product applied to wheat	1000	Kg
Amount of nitrogen applied to wheat as ammonium nitrate (34.5% N)	345	Kg
Area of wheat to which inorganic fertiliser is applied	10	Hectares
Area of cultivated land converted to improved grassland	2	Hectares
Area of wheat sprayed with pesticides (liquids)	10	Hectares
Area of wheat broadcast with pesticides (solids/granules)	10	Hectares
Amount of herbicide used on wheat	2	Kilograms
Amount of fungicide used on wheat	5	Kilograms
Area harrowed	10	Hectares
Area ploughed	10	Hectares
Tonnes of beef output	65	Tonnes Live Weight
Tonnes of barley harvested	0	Tonnes

Figure 3.5.11: Farm Assessment Wizard: Entering quantities

After entering quantities, the user is presented with a screen prior to running the assessment which allows them to set some options that will be used in the process of determining mitigations. Currently these include the option to include fuel/energy source swapping, where the impact of using different fuels is calculated, and the option to fix any of the activities on the farm, so that variations on these are not offered as mitigation options (for example the user may decide that changing their harrow is not something they would consider doing, so they may wish to exclude this as something that can be changed). At this stage, all the options are selected so that all mitigation options will be calculated unless the user makes a selection.

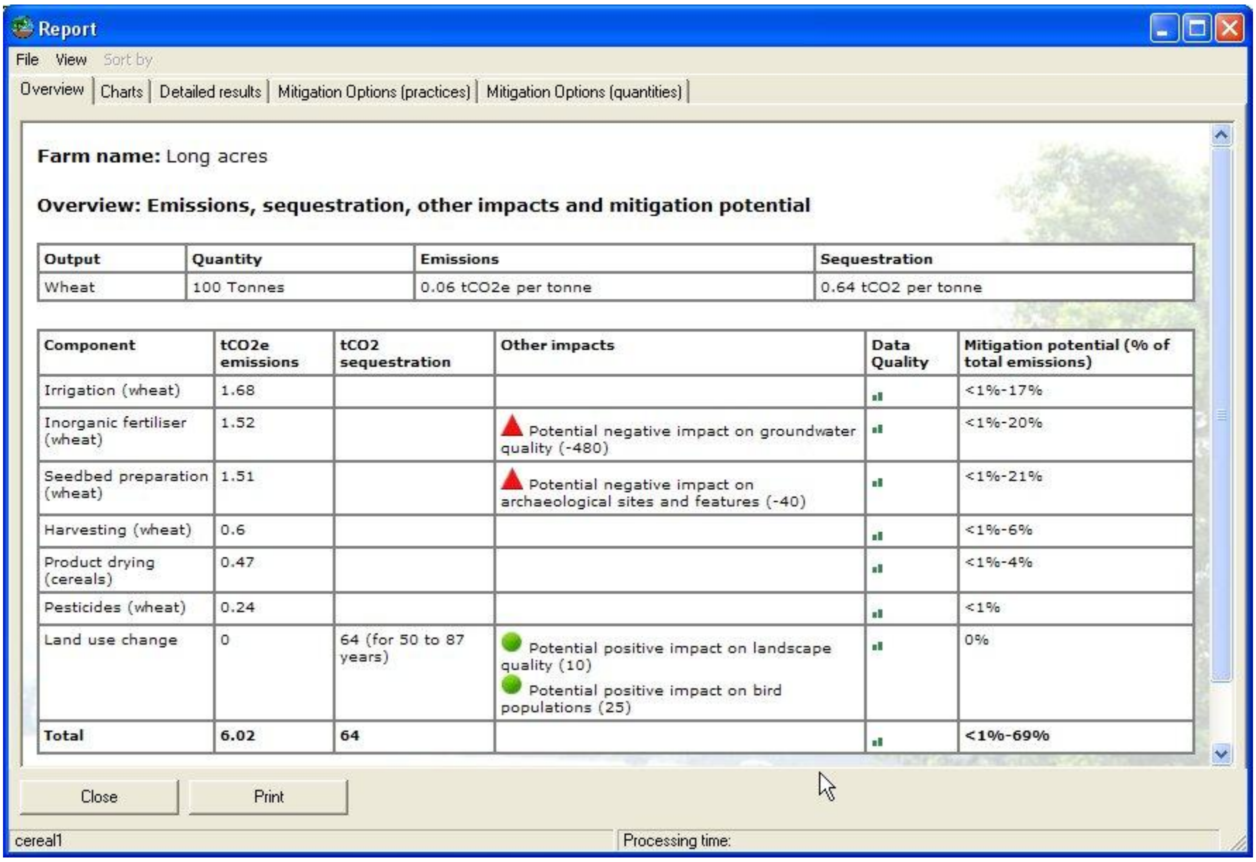
Clicking on Next after the mitigation options settings screen will start the calculation. Currently on some of the more complex farm assessments this can take a couple of minutes to run (especially for calculating all possible combinations for the mitigation options), so progress on the calculations is displayed with a series of progress bars. When the calculations are complete the results screen is shown.

3.5.6.5. Results and reports screens

The results of the assessment are presented in a series of html reports. There are still some areas under development, so the screens shown here only reflect the state of the software at the time of writing this report, so they may be slightly different when the software is released.

There are currently a variety of different (6 or 7 depending on set up options selected) reports ranging from an overview for the farm to detailed results and mitigation options – thus following the philosophy of not immediately bombarding the user with a lot of information and numbers, and allowing them to drill down to more detailed information if required.

The first report screen provides an overview of the results for the farm in the form of a table (see Figure 3.5.12) showing the emissions, sequestration, other impacts and any economic data, for the parent components for the farm. It also shows the data quality behind these results and the scope for mitigation within each component (the potential for reduction of the total emissions for the farm expressed as a percentage).

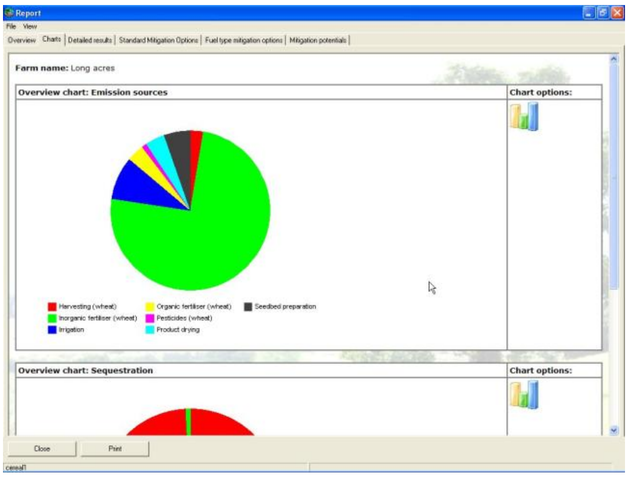


Output	Quantity	Emissions	Sequestration
Wheat	100 Tonnes	0.06 tCO2e per tonne	0.64 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Irrigation (wheat)	1.68				<1%-17%
Inorganic fertiliser (wheat)	1.52		Potential negative impact on groundwater quality (-480)		<1%-20%
Seedbed preparation (wheat)	1.51		Potential negative impact on archaeological sites and features (-40)		<1%-21%
Harvesting (wheat)	0.6				<1%-6%
Product drying (cereals)	0.47				<1%-4%
Pesticides (wheat)	0.24				<1%
Land use change	0	64 (for 50 to 87 years)	Potential positive impact on landscape quality (10) Potential positive impact on bird populations (25)		0%
Total	**6.02**	**64**			**<1%-69%**

Figure 3.5.12: Farm Assessment Results: Overview

Figure 3.5.12 illustrates that the highest emissions are shown at the top of the table and any associated negative or positive other impacts are shown using a red triangle and green circle respectively. The results shown in the overview screen are also presented graphically as charts (see Figures 3.5.13a and 3.5.13b) by selecting the Charts tab at the top of the screen. Results can be displayed as either a pie chart or a bar chart.



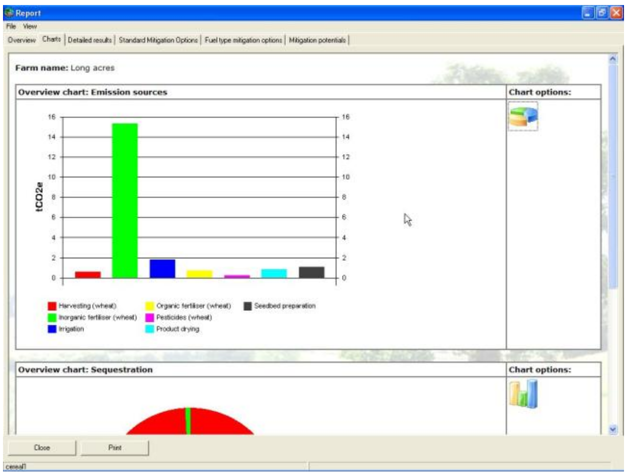
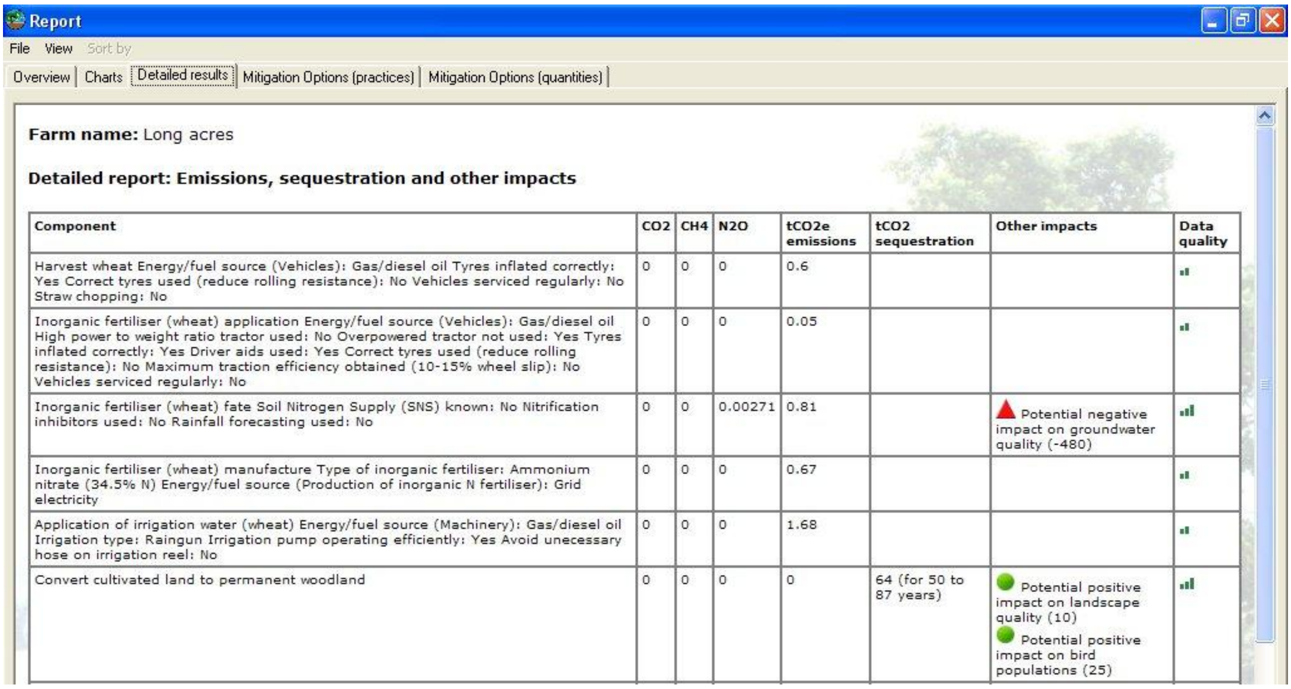


Figure 3.5.13a: Farm Assessment Results: Pie chart **Figure 3.5.13b: Farm Assessment Results: Bar chart**

On the third tab the user can select to view the detailed results for the farm. This table (see Figure 3.5.14) provides details on emissions, sequestration, economic and other impacts for each child component for the farm. As with the overview table, this table contains details on the data quality behind each result.



Component	CO2	CH4	N2O	tCO2e emissions	tCO2 sequestration	Other impacts	Data quality
Harvest wheat Energy/fuel source (Vehicles): Gas/diesel oil Tyres inflated correctly: Yes Correct tyres used (reduce rolling resistance): No Vehicles serviced regularly: No Straw chopping: No	0	0	0	0.6			
Inorganic fertiliser (wheat) application Energy/fuel source (Vehicles): Gas/diesel oil High power to weight ratio tractor used: No Overpowered tractor not used: Yes Tyres inflated correctly: Yes Driver aids used: Yes Correct tyres used (reduce rolling resistance): No Maximum traction efficiency obtained (10-15% wheel slip): No Vehicles serviced regularly: No	0	0	0	0.05			
Inorganic fertiliser (wheat) fate Soil Nitrogen Supply (SNS) known: No Nitrification inhibitors used: No Rainfall forecasting used: No	0	0	0.00271	0.81		Potential negative impact on groundwater quality (-480)	
Inorganic fertiliser (wheat) manufacture Type of inorganic fertiliser: Ammonium nitrate (34.5% N) Energy/fuel source (Production of inorganic N fertiliser): Grid electricity	0	0	0	0.67			
Application of irrigation water (wheat) Energy/fuel source (Machinery): Gas/diesel oil Irrigation type: Raingun Irrigation pump operating efficiently: Yes Avoid unnecessary hose on irrigation reel: No	0	0	0	1.68			
Convert cultivated land to permanent woodland	0	0	0	0	64 (for 50 to 87 years)	Potential positive impact on landscape quality (10) Potential positive impact on bird populations (25)	

Figure 3.5.14: Farm Assessment Results: Detailed results

Finally, the mitigation options above do not provide a comparison to the current farm assessment and thus it is not clear which ones would be of most or least benefit. It shows the potential net benefit of any single change. This is particularly important where there linkages between a modifier class and more than one component, as implementing that change will affect emissions in more than one component, sometimes synergistically but sometimes there are trade-offs, so the net benefit needs to be known.

The potential shown is both in terms of their potential to reduce emissions from the specific component and the farm as a whole (Figure 3.5.15). The mitigation options with the greatest potential are shown at the top (or the report can also be sorted by economics or a combination of mitigation potential and economics). The report also shows changes in any other impacts, negatively or positively, so that the user can see where there are synergies and trade-offs between emissions reductions and other environmental impacts.

For example, Figure 3.5.15 shows that using nitrification inhibitors will reduce greenhouse gas emissions (by reducing N_2O emissions) and this is often correlated with an associated reduction in nitrate leaching and thus there are benefits to groundwater quality.

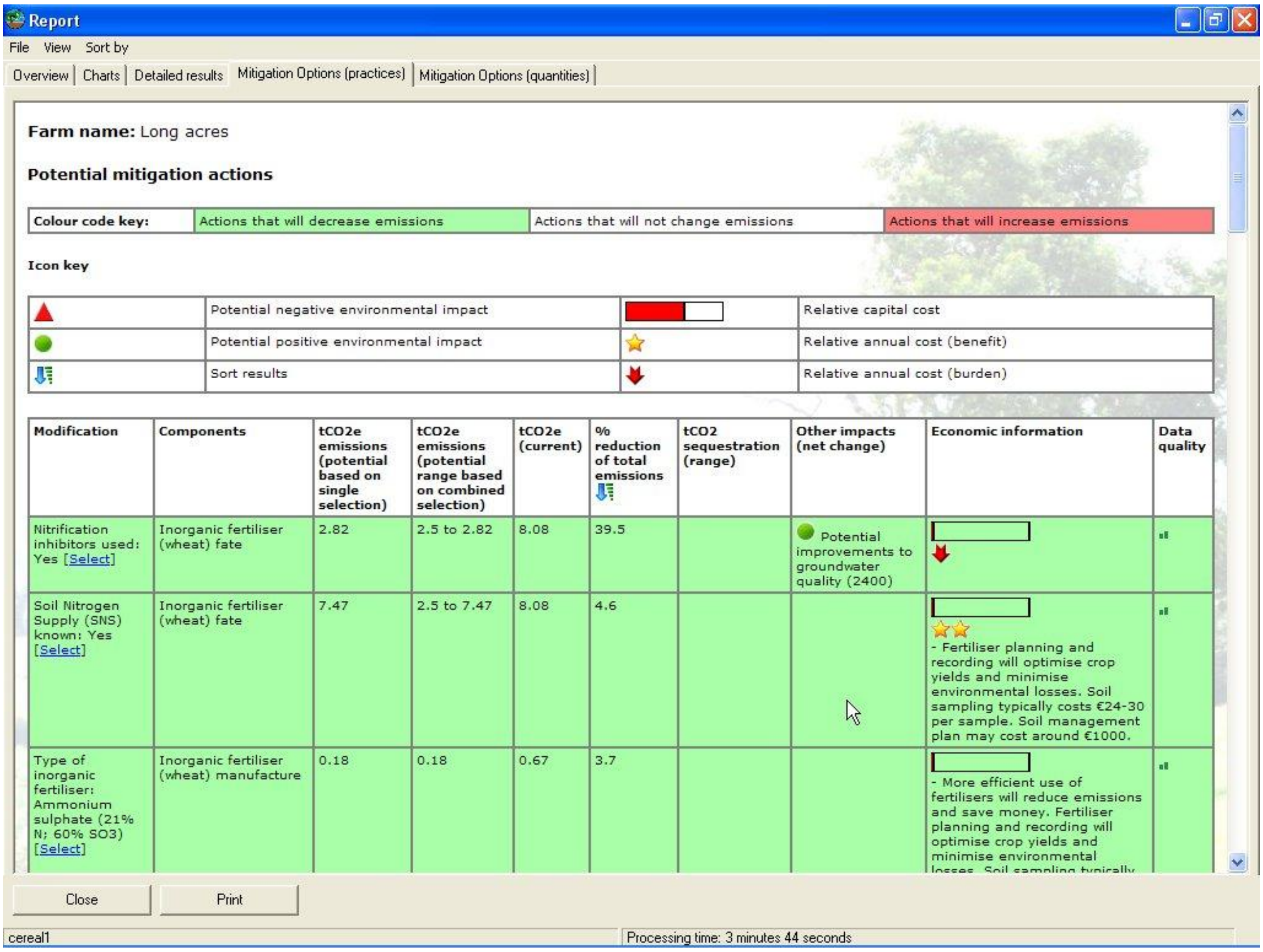
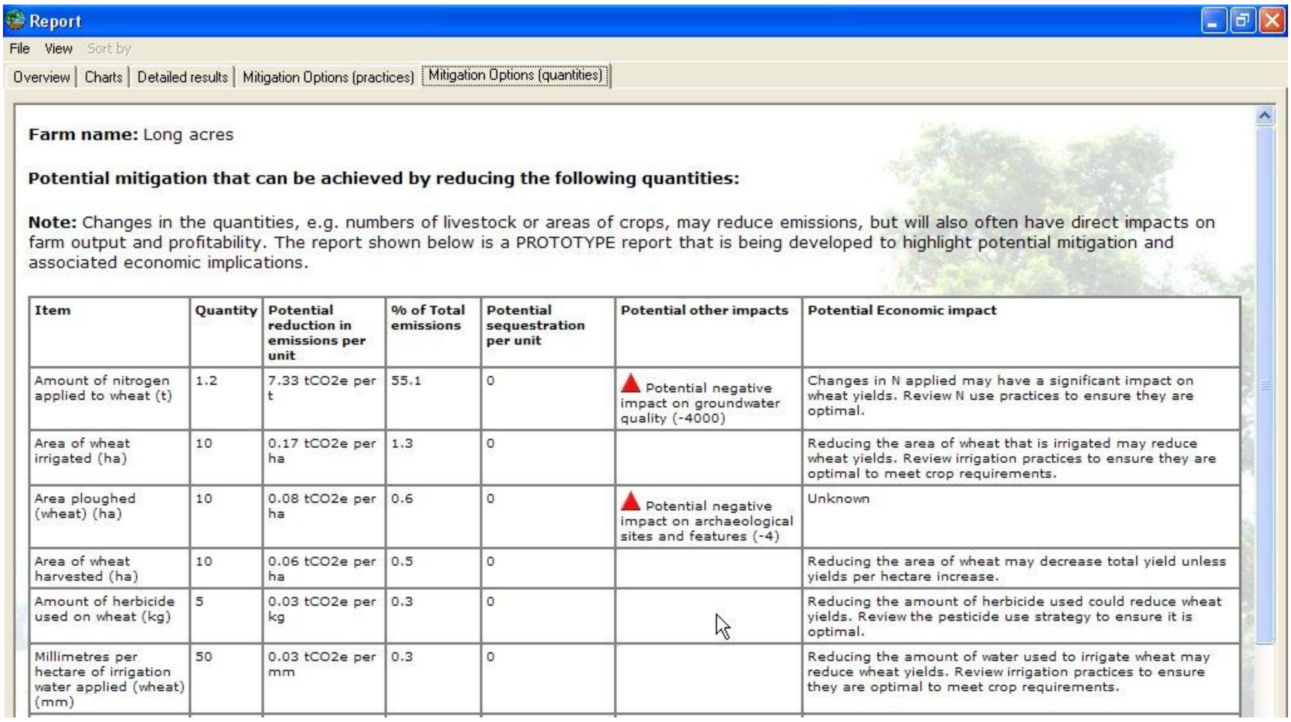


Figure 3.5.15: Farm Assessment Results: Mitigation potential (practices)

In the left hand column, there are options to select some of the mitigation options suggested. Clicking on select add each option to a list, which can then be implemented for the current farm assessment and then the calculations can be run again to see the impact on emissions of the implemented options. As such it is envisaged that the user may engage in an iterative process to refine and select mitigation options. For example, after seeing the initial results the user may determine that there are some components that they do not want or need to change on their farm, and thus choose to exclude them as potential mitigation options from the results (by locking them). Therefore what could start off as a long list of mitigation options may become refined and shortened, thus focusing the user on those options that are most relevant and practical for their situation.

The final report (on the right most tab) presents potential mitigation that may be achieved by adjusting the quantities entered for the farm, such as amount of fertiliser used, area of crops or livestock numbers (see Figure 3.5.16).



Farm name: Long acres

Potential mitigation that can be achieved by reducing the following quantities:

Note: Changes in the quantities, e.g. numbers of livestock or areas of crops, may reduce emissions, but will also often have direct impacts on farm output and profitability. The report shown below is a PROTOTYPE report that is being developed to highlight potential mitigation and associated economic implications.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to wheat (t)	1.2	7.33 tCO2e per t	55.1	0	Potential negative impact on groundwater quality (-4000)	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area of wheat irrigated (ha)	10	0.17 tCO2e per ha	1.3	0		Reducing the area of wheat that is irrigated may reduce wheat yields. Review irrigation practices to ensure they are optimal to meet crop requirements.
Area ploughed (wheat) (ha)	10	0.08 tCO2e per ha	0.6	0	Potential negative impact on archaeological sites and features (-4)	Unknown
Area of wheat harvested (ha)	10	0.06 tCO2e per ha	0.5	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Amount of herbicide used on wheat (kg)	5	0.03 tCO2e per kg	0.3	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Millimetres per hectare of irrigation water applied (wheat) (mm)	50	0.03 tCO2e per mm	0.3	0		Reducing the amount of water used to irrigate wheat may reduce wheat yields. Review irrigation practices to ensure they are optimal to meet crop requirements.

Figure 3.5.16: Farm Assessment Results: Mitigation potential (quantities)

The potential reduction in emissions associated with each quantity are shown and expressed per unit, along with any other potential impacts. Clearly changing areas of crops, livestock numbers or any other quantities, could have potentially significant impacts on the output and economic viability of the farm. Therefore, alongside the emissions and impacts are notes about the potential economic impact that such a change in the quantity could result in.

3.5.6.6. IMPACCT Policy Assessment

The Policy Assessment interface within the software provides a facility for undertaking the policy opportunities analysis (Task 5). The underlying principle is to compare a baseline scenario with a future scenario, in order to see how emissions may be reduced. This comparison could be for a specific local area (or even an individual farm), a region, a country or the whole of Europe.

Figure 3.5.17 shows the main entry screen for the Policy Assessment tool, when an existing policy project has been opened or created, which shows a summary of the policy assessment project.

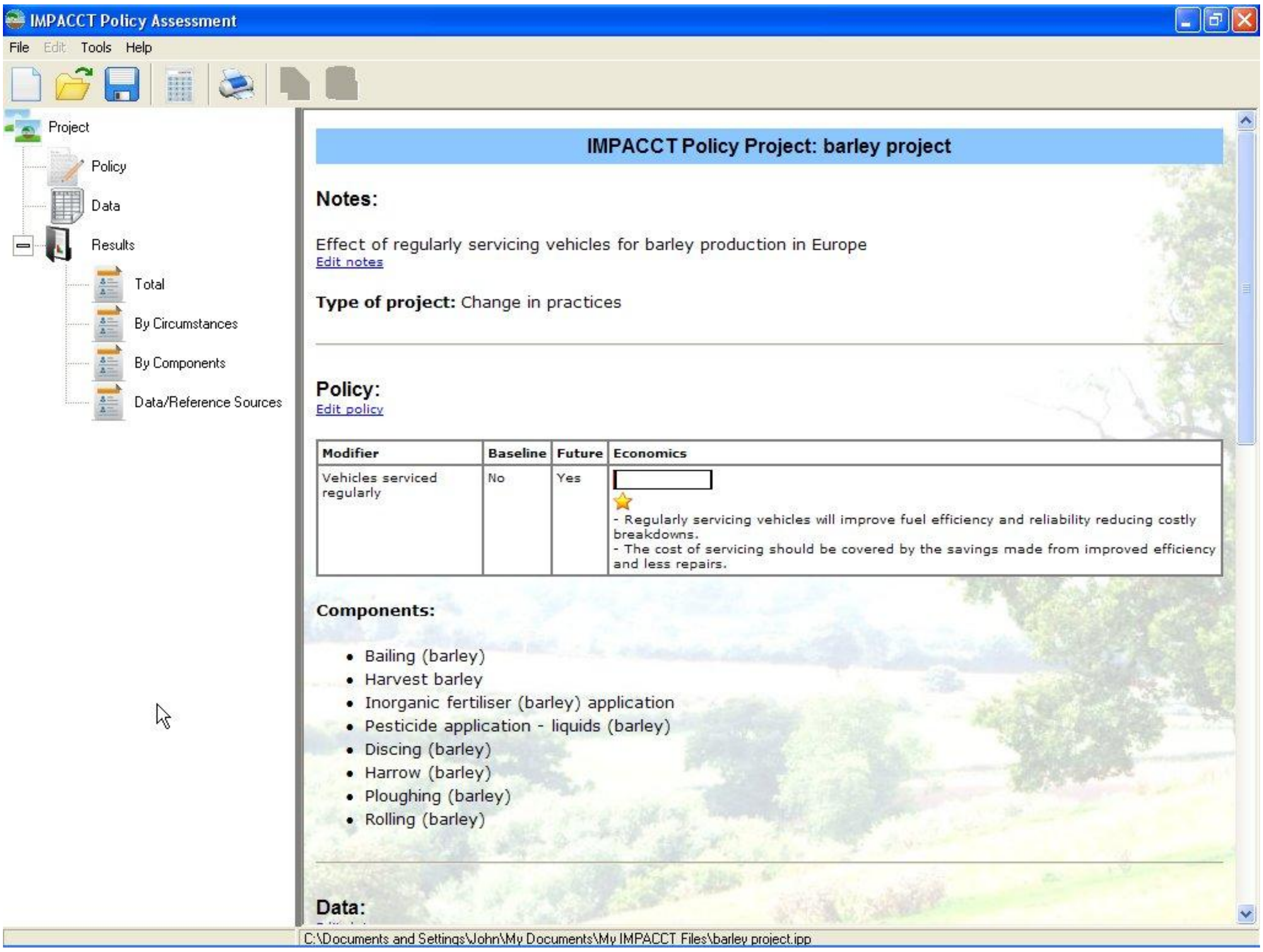


Figure 3.5.17: Policy Assessment Tool: Project summary screen

Beyond the policy project summary screen, there are essentially 3 parts to a policy project:

1. Policy Scenario Builder
2. Data entry
3. Results

1. Policy Scenario Builder

The Policy Scenario Builder allows the user to select what type of project they wish to conduct and then construct (or choose) baseline and future scenarios. There are two types of project: practice-based and numbers-based:

- A practice-based project is when a policy advocates a change in practice(s). For example, changing from a ploughing depth of 25cm to 15cm. This type of project requires both a baseline and future scenario to be selected/created (using the example above, the baseline would be ploughing at 25cm and the future would be ploughing at 15cm). It also requires the numbers/quantities for baseline and future scenarios, so that the degree of adoption of the practice in the baseline and future scenarios can be determined.

- A numbers-based project is when there is only a change in the quantities of a particular component (e.g. area of crops or livestock numbers). This type of project only requires a baseline scenario to be created, as the future scenario is determined by the change in numbers.

Figure 3.5.18 shows the policy scenario builder screen.

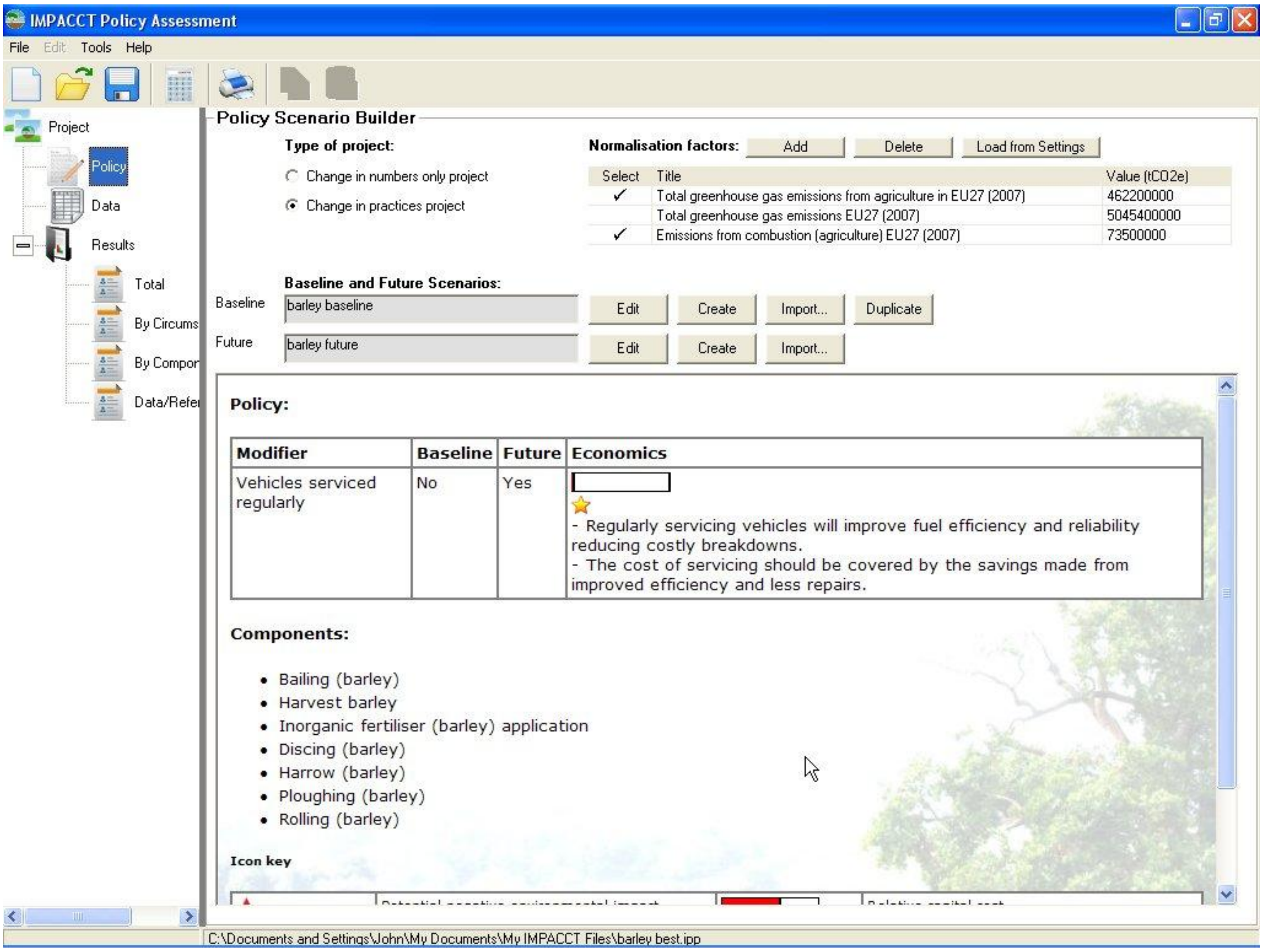


Figure 3.5.18: Policy Project: the policy scenario builder

The same data is required for policy assessments as for farm assessments, so rather than develop a new interface for data entry, the Farm Assessment Wizard (see above) is utilised for creating and editing baseline and future scenarios. This also has the advantage that data can be imported from previously created farm assessments, to form the basis of a policy scenario (e.g. if a mitigation option was identified during a farm assessment, then this could be imported into a policy project). Once the user has a selected a baseline and future scenario, a summary of the policy is displayed (see Figure 3.5.18). For numbers only projects, where only a baseline scenario is selected, the display is slightly different (as shown in Figure 3.5.19).

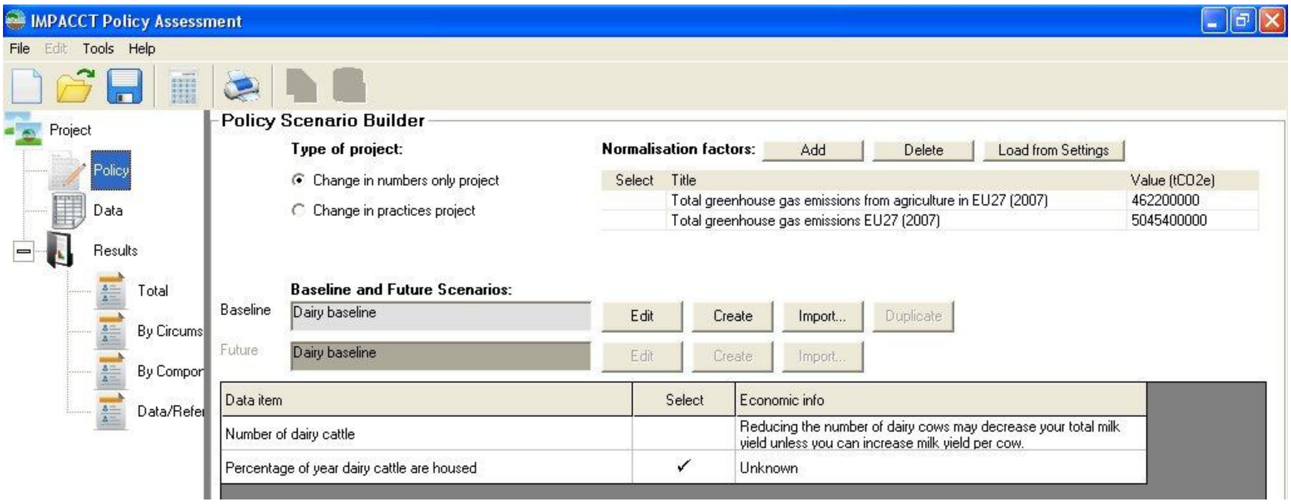


Figure 3.5.19: Policy Project: data item selection for numbers-based projects

For numbers-based projects, the user selects/creates a baseline scenario and then selects which data items they wish to alter as part of the policy assessment, by ticking the appropriate boxes next to the relevant data items.

The Policy Scenario Builder also allows the user to set Normalisation factors. These can be set in the Settings of the software or directly entered here. These normalisation factors are then used in the results to place the emissions in context (e.g. percent reduction compared to total emissions for Europe).

2. Data entry

Once the policy scenario has been defined, data for the assessment needs to be entered. In order to conduct an assessment for a particular region or country, data for the relevant components and data items needs to be entered based on any fixed modifiers for the components selected. Fixed modifiers include aspects such as location, soil type, rainfall, etc. and will influence emissions and other impacts. So data needs to be entered against these variables (if available). Figure 3.5.20 shows an example for barley for a number of different field operations

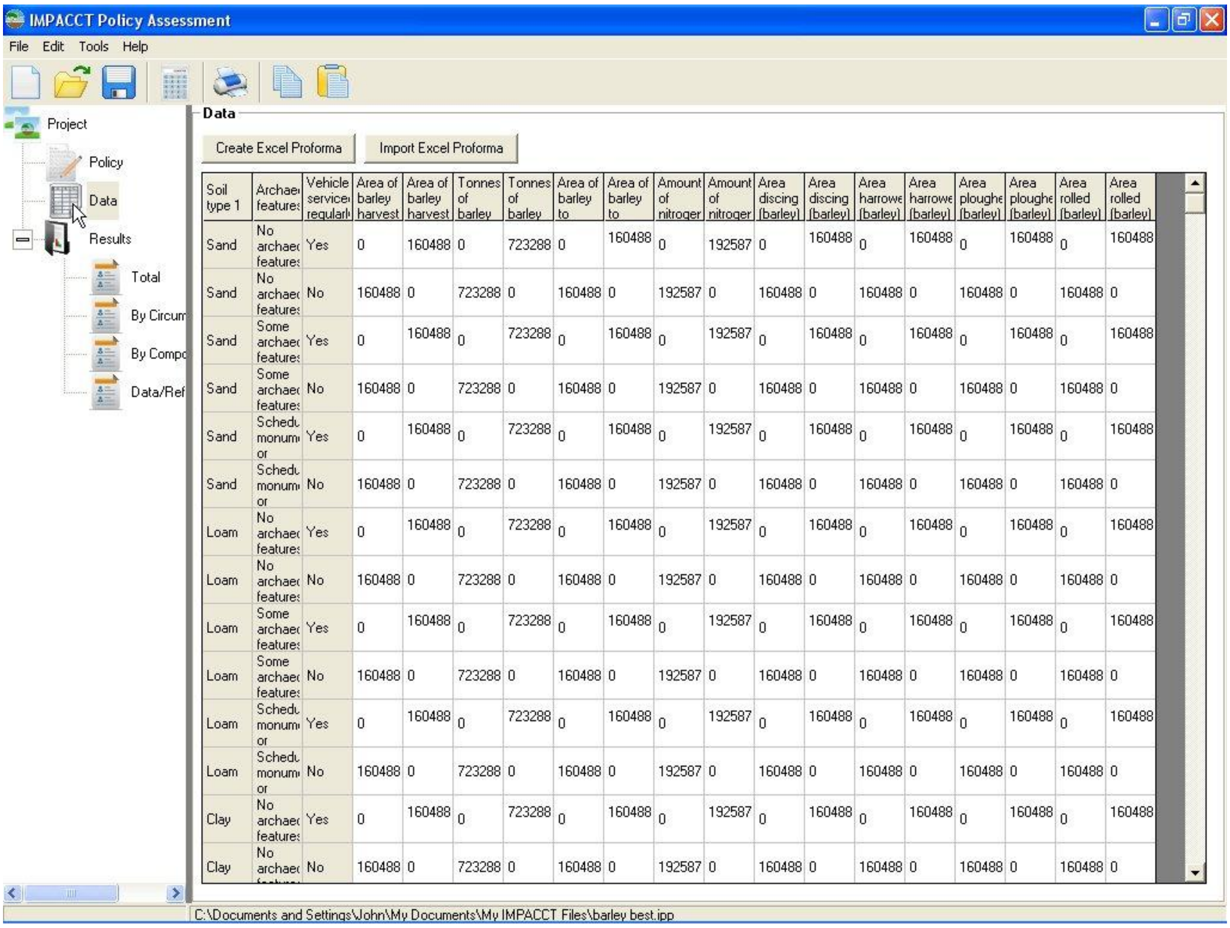


Figure 3.5.20: Policy Project: data entry (practice-based project)

In Figure 3.5.20 data needs to be entered based on split between different combinations of soil types and archaeological features (as these will affect emissions and other impacts). In the case of number-based projects, data for baseline and future scenarios needs to be entered as shown in Figure 3.5.21.

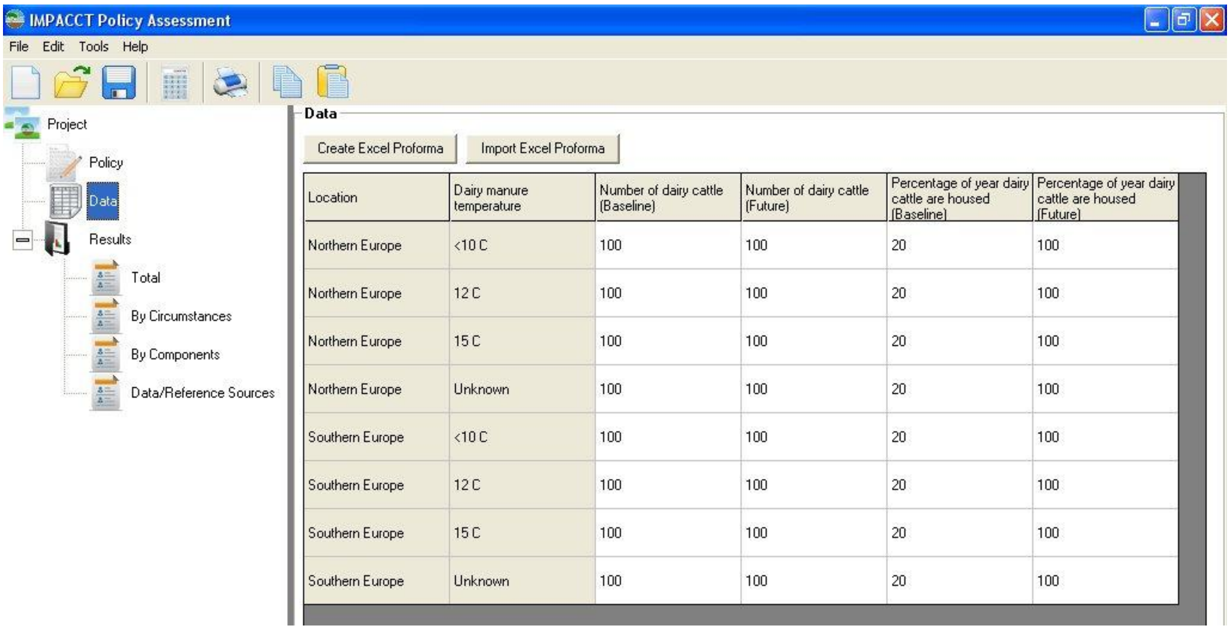


Figure 3.5.21: Policy Project: data entry (numbers-based project)

3. Results

Once the data has been entered, the emissions and other impacts can be calculated and then viewed in the results section. The results can be viewed in one report by clicking on the Results icon in the tree on the left, or can be viewed in 4 individual reports below the Results icon.

The first report (see Figure 3.5.22) shows the overall impact of the policy in terms of emissions and other impacts.

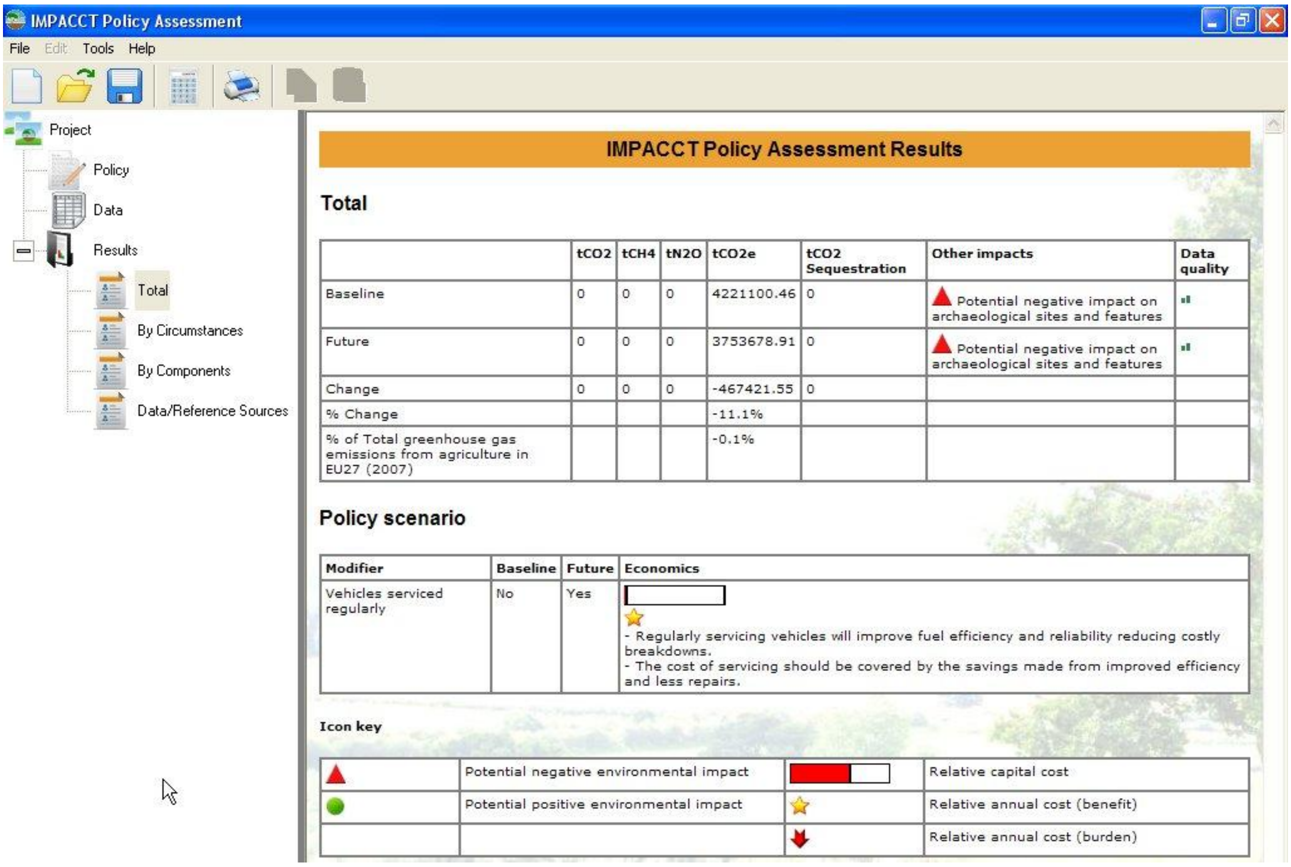


Figure 3.5.22: Policy Project: results (total)

This report also provides a summary of the policy including any economic information, which is important with respect to any barriers or incentives for adopting the policy.

The second report (see Figure 3.5.23) provides a detailed breakdown of results across all the variables (circumstances) identified in the data entry screen, showing both the baseline (B) and future (F) results for each set of circumstances.

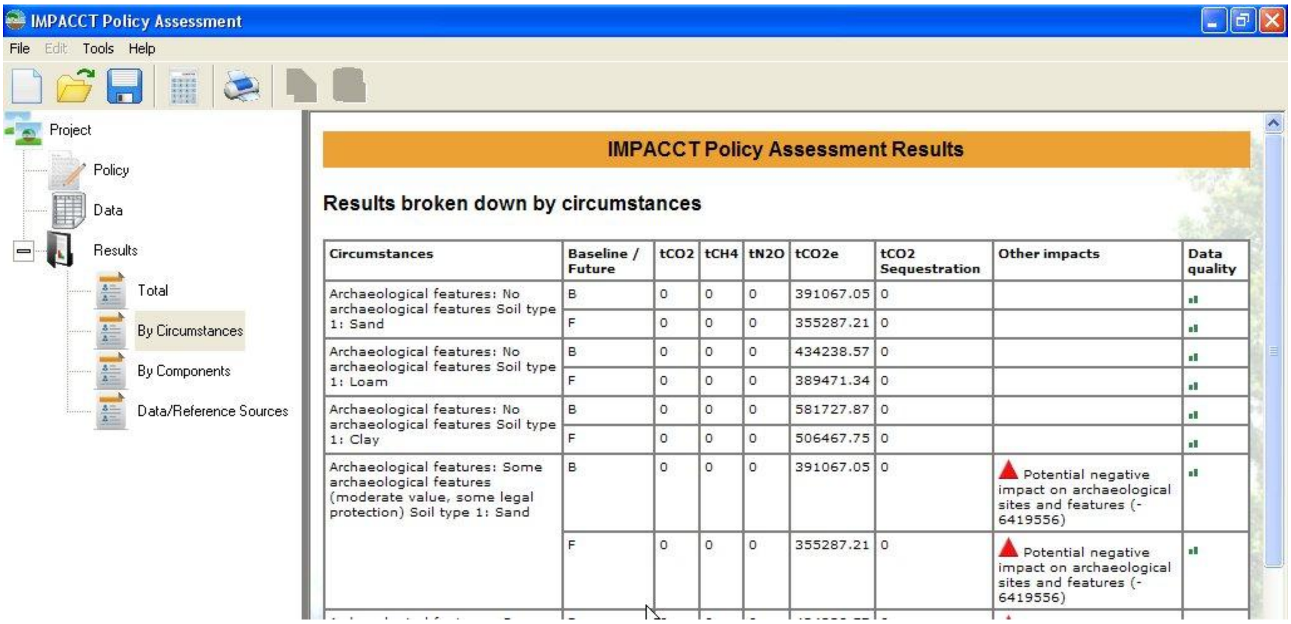


Figure 3.5.23: Policy Project: results (breakdown by circumstances)

The third report (see Figure 3.5.24) provides a similar breakdown by components and the fourth report provides a list of the reference and data sources (from the core database) used in the calculation.

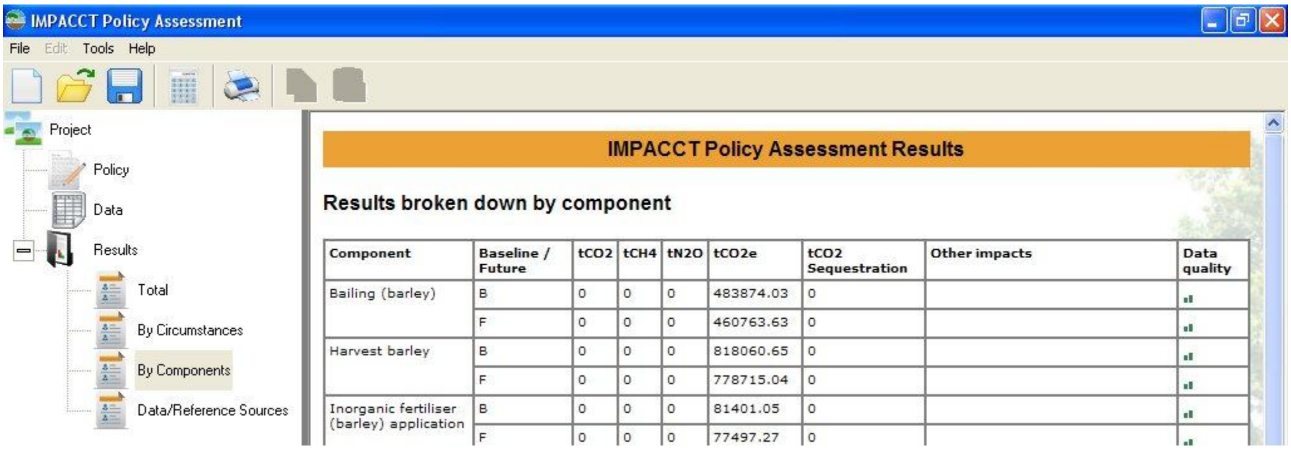


Figure 3.5.24: Policy Project: results (breakdown by components)

These outputs will provide the basis on which to assess the likely impact of any proposed policies, including the potential for widespread adoption and any barriers preventing adoption.

As described above, the Farm Assessment Wizard can be used as a means of identifying mitigation options that may have the potential to be adopted as wider policies. In addition to the wizard, there is also a Database Search facility (within the Toolbox of the IMPACCT software) that allows the user to explore data in the core database, and this can also be used as a basis for determining which policies to assess within the Policy Assessment facility.

3.5.6.7. Database Search

The Database Search facility can be found within the Toolbox of the IMPACCT software and provides an interface to the core database that underlies the software. Figure 3.5.24 shows the main database enquiry screen.

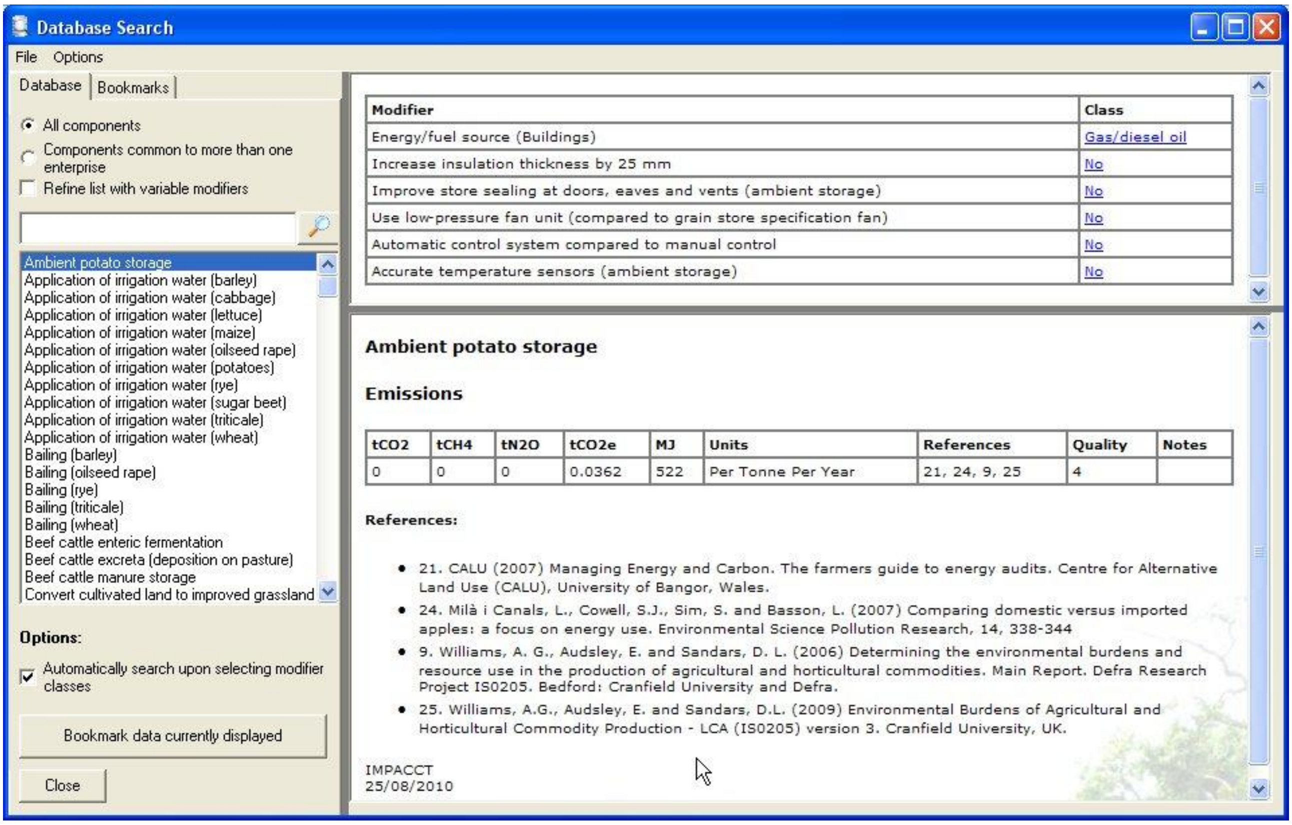


Figure 3.5.25: Database Search

The user can browse or search list of farm components and then clicking on a component will display data for that component in the right-bottom frame. Variations in that data can then be viewed by selecting different combinations of modifier classes in the top-right frame. Alternatively, the user can select to view the range of emissions data (from the Options menu) – see Figure 3.5.26.

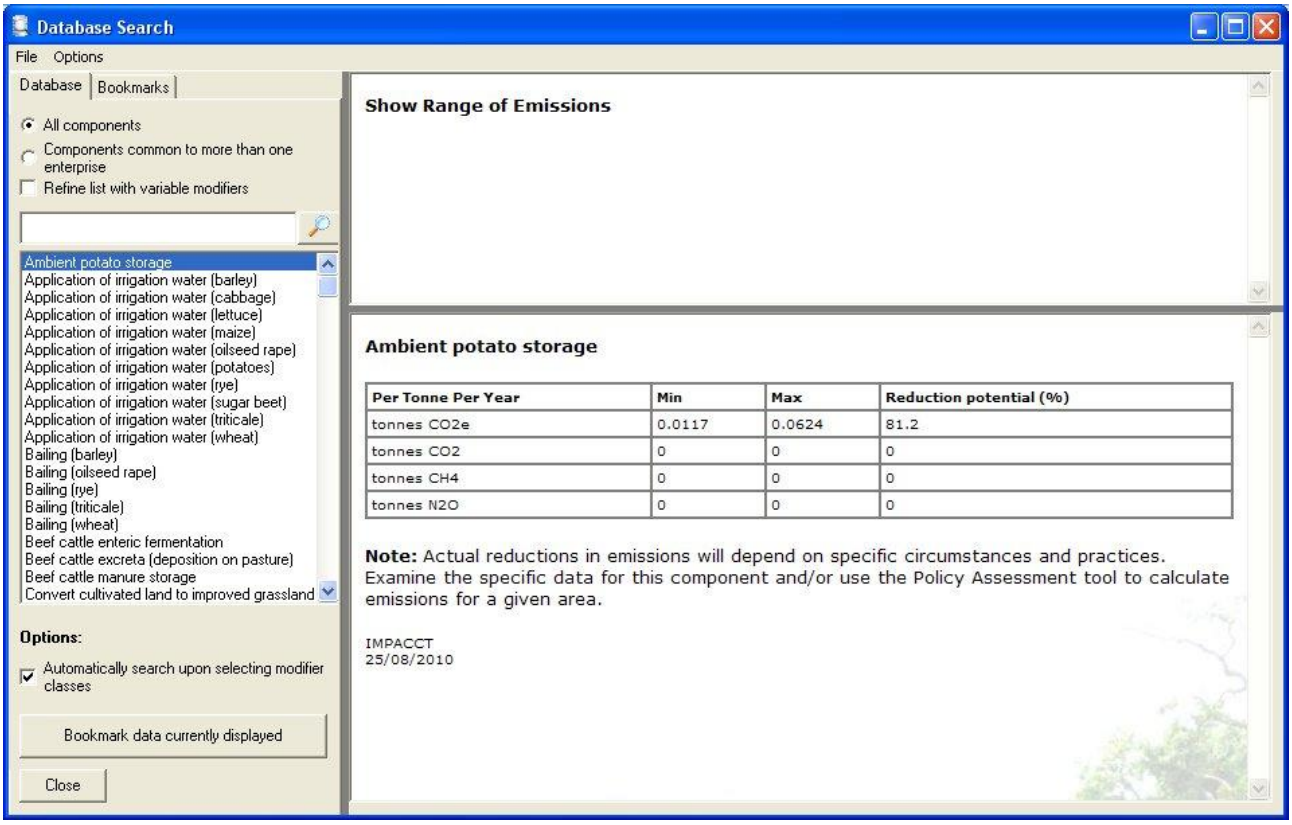


Figure 3.5.26: Database Search: Data range

The user can also choose to select those components that apply to more than one type of farm enterprise. This can be useful when searching to mitigation options for components that have the potential for more widespread adoption (i.e. those components which apply to multiple types of enterprises may have potential for widespread adoption than those that are very specific to a single enterprise). Additionally, the user can choose to refine the list by using variable modifiers (see Figure 3.5.27).

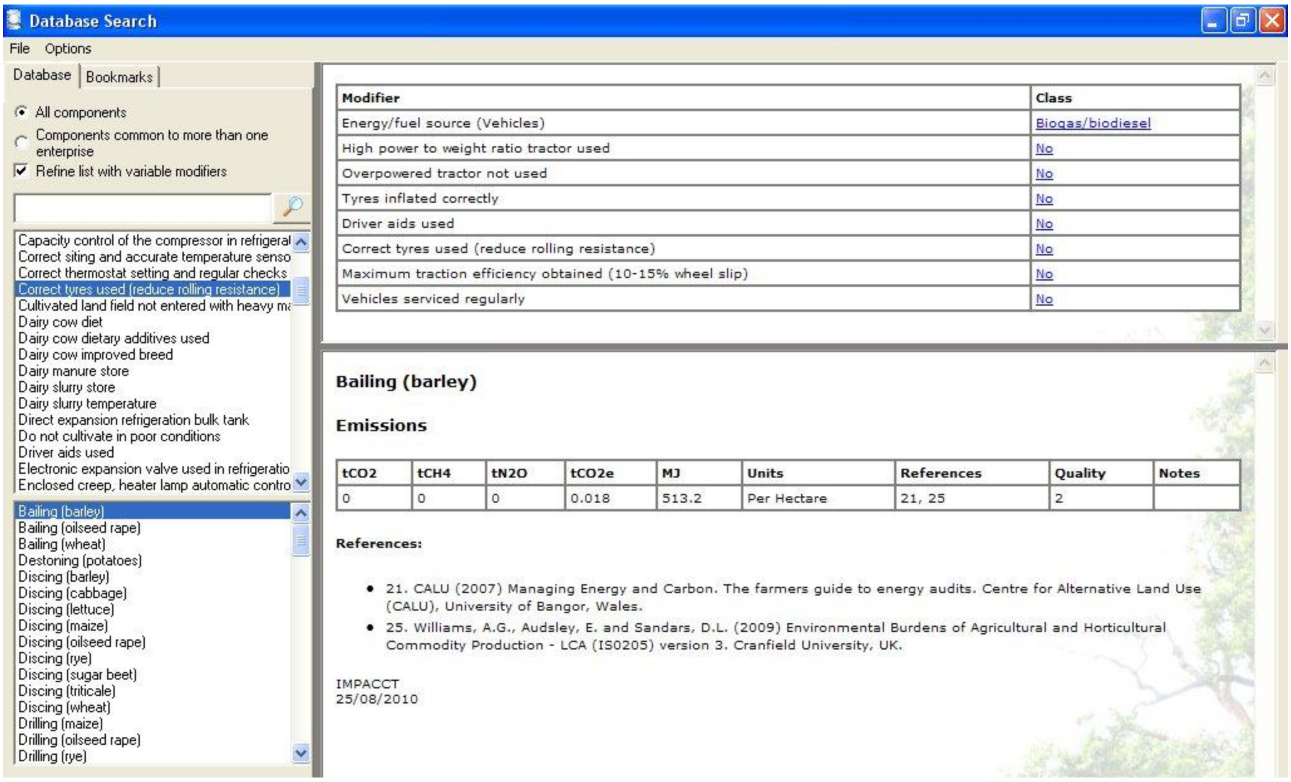


Figure 3.5.27: Database Search: Using variable modifiers to search for components

In Figure 3.5.27, we can see that selecting to use the 'correct tyres' as a mitigation option, impacts a large range of components (different field operations for different crops). Therefore, this helps identify that this particular option may also have potential for widespread adoption.

Finally, there is also a bookmarking facility within the Database Search tool that allows the user store bookmarks in the database. This is useful given the huge number of emission factors in the database (~ 200K factors).

3.5.6.8. Settings and software updates

The software, like many other applications, has a settings and options area. This allows the user to customise (to a limited extent) and set default settings for their application. The settings area also has a facility to check and automatically download updates for the software (see Figure 3.5.28). These updates include the core database, the software core and the updater tool itself.

When the software identifies that updates are available (using and update server), the user can then click a button to download them – they will then be automatically downloaded and installed.

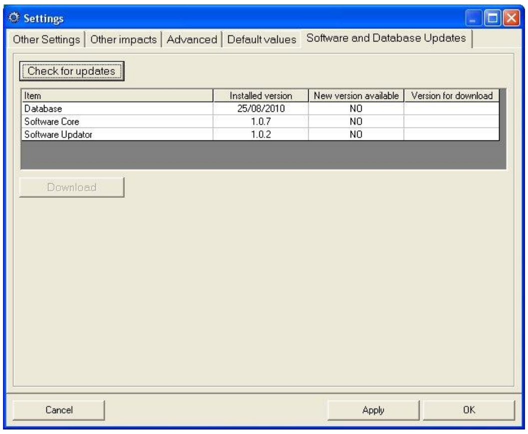


Figure 3.5.28: Check and download updates

3.6. Task 5: Policy opportunities

Activity Start Date	M6	Activity Finish Date	M9
Milestones and Deliverables			
Key project partners involved	University of Hertfordshire		

3.6.1. Introduction

This Task has involved using the Policy Assessment tool within the IMPACCT software (see Section 3.5.6) and therefore this task also forms part of Task 6 (Proofing the model) as it is an application and test of the model.

The main policy aim of this project has been to develop a model that can help reduce/mitigate the emission of greenhouse gases from agriculture. The potential contribution of the IMPACCT model towards this aim is two-fold:

- Firstly, it can be used by farmers and their advisers/consultants to identify opportunities on the farm to reduce emissions without adversely affecting economic performance or other environmental objectives.
- Secondly, the model can be used by policy makers to help identify and evaluate potential policies which may reduce emissions from agriculture and/or identify any potential barriers to the adoption of such policies, such as economic or other impacts associated with any potential mitigation strategies.

The first of these is examined in Activity 5.1 under the heading of knowledge transfer and second is explored in Activities 5.2 and 5.3, potential for widespread adoption and barriers to adoption respectively.

3.6.2. Activity 5.1. Knowledge transfer

In order for any industry to evolve in a more sustainable direction it is essential that the stakeholders within that industry are armed with the latest information and knowledge, and the agricultural is no different in this respect. There have been numerous 'revolutions' in agriculture fed by advances in science and technology. But such revolutions, and evolutions, do not happen if knowledge, information and data are not successfully communicated and transferred into the industry.

Mechanisms for information and knowledge transfer, often referred to as extension communication, are diverse and multi-faceted. It is widely recognised that a single means of communication rarely succeeds in delivering messages to all relevant stakeholders in agriculture – this is due to the diversity of stakeholders and their individual circumstances and preferences. Instead a suite of measures is often required in order to engage this diverse audience. This suite may include, for example, simple paper leaflets, best practice guides, audio or video demonstrations/shows, workshops, farm visits and conferences, networking opportunities, one-to-one advice and guidance, websites and software applications. It is the latter of these that has been explored within this project. However, an important aspect that needs to be considered is integration. Any programme of communication to bring about improvements in practices needs to be integrated, so that the range of communication techniques, from the paper leaflets to computer software (above), are telling the same story.

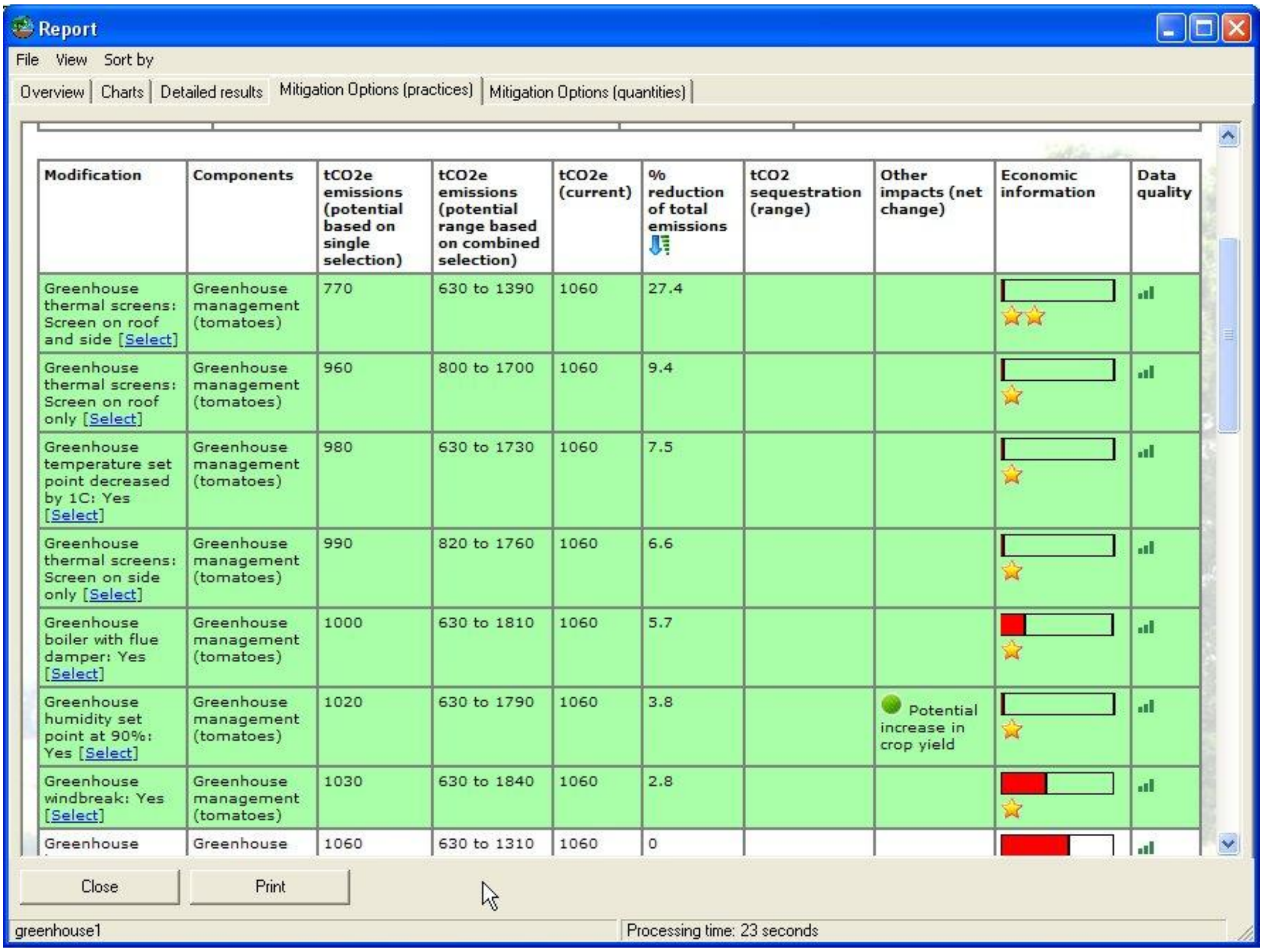
The IMPACCT Farm Assessment tool developed within this project has been designed and developed for use by farmers and their advisers. It is acknowledged that not all farmers like to use computer software and models, some distrust IT applications, and many are not computer literate, and some of these perceptions may be evident in the feedback received from the Phase 2ii case studies (see Section 3.5.1). However, there is a role for computer models in modern agriculture, especially when dealing with complex issues or when large amounts of information and data need to be considered. Finding the right 'pathway' through such complexity is where software applications have their greatest potential. However, it is important to acknowledge and recognise the 'line' between decision support and decision making.

When trying to 'navigate' through the complex issues surrounding decisions to made on farms, there is often a desire to find the 'magic bullet', the single answer that resolves everything, and in the past some software applications have attempted to model issues and provide such answers, i.e. "you should do X". However, in so doing such an approach is often their undoing, as often, particularly with complex issues, there is never a single answer, and consequently the single answer provided by the application may often be wrong resulting distrust in the application. Hence it is important to recognise that a software application cannot 'make a decision', and that the 'line' needs to be brought back from decision making to decision support, and the goal is to provide the user with options to help them make a 'more informed' decision and not be too prescriptive in the outputs presented.

This has been the approach of the IMPACCT Farm Assessment, to draw upon a large amount of data and information relating to mitigating greenhouse gas emissions and then present a range of options to the user based on the data and information available. It is not possible to prescribe an exact plan of action for a farm as this requires detailed information that is simply not available with a tool such as this. However, it is possible to explore the data and knowledge available and point users in some of the key directions that they may wish to explore as part of forming a plan of action (perhaps as part of a consultation process with an adviser).

What is lacking from the IMPACCT software is perhaps the 'next step'. Having identified a number of potential mitigation options, what should the farmer do next? Feedback from the Phase 2ii case studies (see Section 3.5.1) has highlighted that the outputs from the IMPACCT model (the reports) are perhaps a bit too 'raw', and may benefit from further interpretation and/or supporting guidance. Such feedback was anticipated in the original project proposal as it was beyond the scope and resources of this project to fully incorporate a broad range of guidance into the 'tentative' model. However, it would be possible to do, and possible to be done in a way that integrates with other communication activities.

The IMPACCT Farm Assessment can be viewed as a means by which advice and guidance could be more targeted. At the moment when the user undertakes an assessment, they are presented with a number of potential mitigation options. For example, Figure 3.6.1 shows the results for a tomato crop grown in a greenhouse.



Modification	Components	tCO2e emissions (potential based on single selection)	tCO2e emissions (potential range based on combined selection)	tCO2e (current)	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Greenhouse thermal screens: Screen on roof and side [Select]	Greenhouse management (tomatoes)	770	630 to 1390	1060	27.4				
Greenhouse thermal screens: Screen on roof only [Select]	Greenhouse management (tomatoes)	960	800 to 1700	1060	9.4				
Greenhouse temperature set point decreased by 1C: Yes [Select]	Greenhouse management (tomatoes)	980	630 to 1730	1060	7.5				
Greenhouse thermal screens: Screen on side only [Select]	Greenhouse management (tomatoes)	990	820 to 1760	1060	6.6				
Greenhouse boiler with flue damper: Yes [Select]	Greenhouse management (tomatoes)	1000	630 to 1810	1060	5.7				
Greenhouse humidity set point at 90%: Yes [Select]	Greenhouse management (tomatoes)	1020	630 to 1790	1060	3.8		Potential increase in crop yield		
Greenhouse windbreak: Yes [Select]	Greenhouse management (tomatoes)	1030	630 to 1840	1060	2.8				
Greenhouse	Greenhouse	1060	630 to 1310	1060	0				

Figure 3.6.1: Farm Assessment Results: Tomato Crop – potential for knowledge transfer

Amongst the suggested mitigation options are use of thermal screens, changes in set-points and the use of windbreaks. This data has been drawn from the core database which was populated using a small number of model runs of the GREENERGY software (GREENERGY, 2008; Korner et al., 2007). This is quite a complex model and also includes a crop model and therefore the user may benefit from using this tool to undertake more detailed modelling of what the impact of adopting some of the suggested mitigation option might be. Therefore, there is scope, possibly within the results report, to have a link to further information (as the reports are in an html format it is technically possible to put direct links to websites, e.g. we could link to the GREENERGY project website: www.greenergy-project.com). It may also be possible to include links to other related guides and leaflets, either in electronic format or where to obtain hard copy versions from, thus providing that more integrated approach to communication mentioned above.

Another example is shown in Figure 3.6.2, where a suggest mitigation option is to calculate the Soil Nitrogen Supply (SNS) as part of calculating fertiliser recommendations.

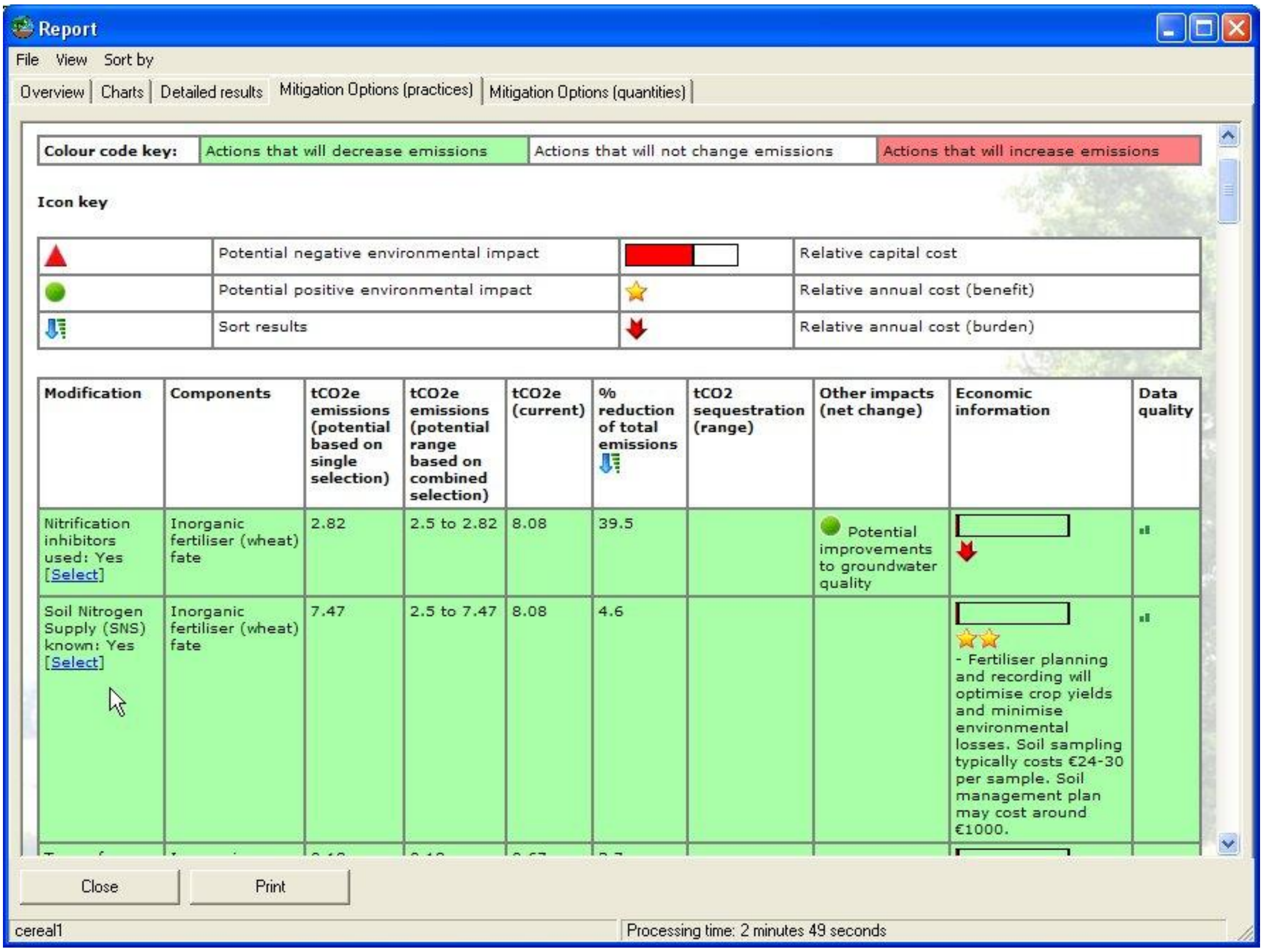


Figure 3.6.2: Farm Assessment Results: Soil Nitrogen Supply (SNS) – potential for knowledge transfer

In this instance, some farmers may not know what SNS is, but it is possible to directly provide this information. For example, there could be link to a detailed explanation of SNS, such as that which is available in Defra's 2010 Fertiliser Manual (MAFF, 2000). This document is available in html format on the ADLib service (www.adlib.ac.uk, Tzilivakis and Lewis, 2007) and so it is possible to directly link to an individual page (rather than the whole PDF, which is 256 pages) as shown in Figure 3.6.3.

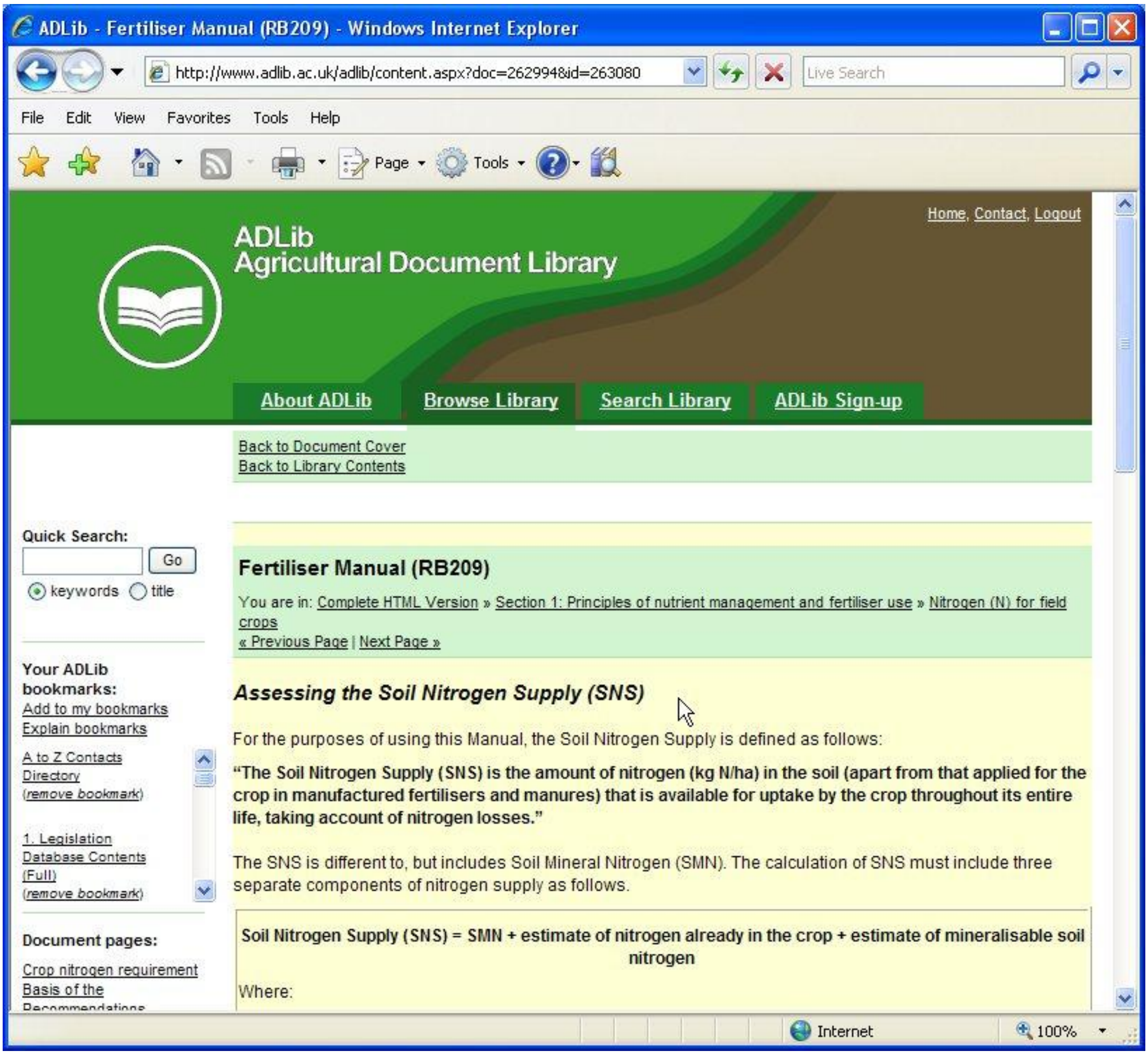


Figure 3.6.3: Potential for knowledge transfer - ADLib guidance: Soil Nitrogen Supply (SNS)

The examples above clearly show how advice and guidance can be valuably targeted towards the requirement of different users. In an information age with rapidly changing societal demands, agricultural businesses need the tools and information to be able to respond, and most importantly they need to be able to find the way to the exact information they need. Tools which embrace this challenge will ultimately prove their value by helping agricultural and horticultural businesses evolve in a more sustainable direction, by providing and/or directing them to the information they need to adapt and respond.

3.6.3. Activities 5.3 and 5.4. Potential for widespread adoption and barriers to adoption

The potential of any specific mitigation options and practices to reduce emissions from agriculture is dependent on how widely they are adopted in the industry combined with the degree of mitigation that they offer. The ideal mitigation option is one that significantly cuts emissions on a large of number of farms and is easily implemented on those farms without any adverse economic or other environmental impacts. However, the diversity of farms and practices, and the nature of greenhouse gas emissions from those practices, means such a 'utopian' mitigation option does not exist. Instead we have a spectrum of options ranging from those that have the potential to make significant reductions in emissions, but on a limited number of farm types and/or with barriers to their implementation, to options that have potential for relatively low reductions in emissions but on a broad range of farm types with limited barrier to their implementation.

Activities 5.3 and 5.4 have explored the potential for widespread adoption and any barriers to adoption using the IMPACCT Policy Assessment tool. A number of examples have been explored, but it should be noted that the Policy Assessment tool is a prototype and model overall is 'tentative', so the results below should be viewed with this in mind.

In order to determine what practices might be suitable for widespread adoption we need to consider any farm components that are common to multiple farm enterprises and/or what practices are common to multiple farm components/enterprises. In the database search tool, there is an option to display only those components that are common to one or more enterprises, as shown in Figure 3.6.4.

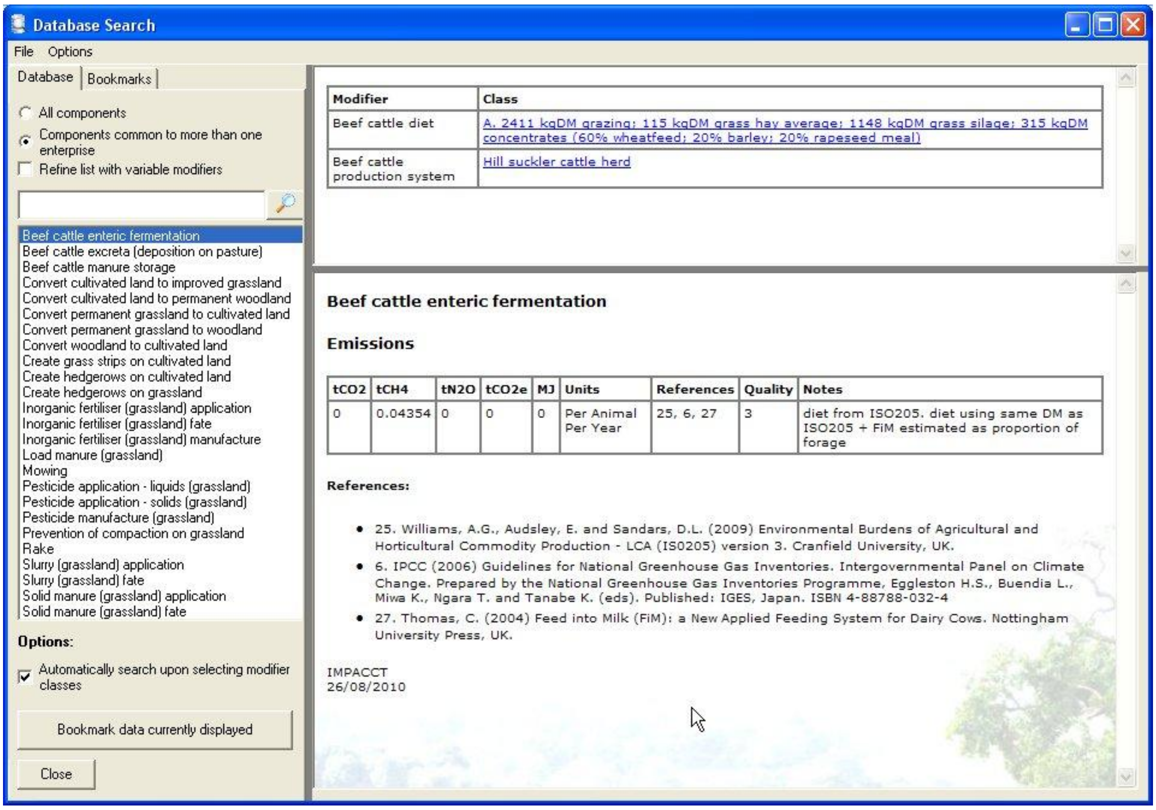


Figure 3.6.4: Database search: components common to multiple enterprises

As Figure 3.6.4 shows, the number of common components is limited to land use and environmental features, and some grassland and livestock components that are common to livestock enterprises. So this does not appear to be a mechanism by which to identify options for widespread adoption.

However, if we examine the variable modifiers (mitigation practices) that are common to one or more components, the results are more useful for identifying options for widespread adoption. Table 3.6.1 shows the current list of variable modifiers in the IMPACCT core database and the number of farm components they are linked to, listed in descending order.

Table 3.6.1: Variable modifiers (practices) sorted by the number of farm components they potentially influence

Variable modifiers	Number of components
Energy/fuel source (Vehicles)	137
Correct tyres used (reduce rolling resistance)	108
Tyres inflated correctly	108
Vehicles serviced regularly	108
Driver aids used	102
High power to weight ratio tractor used	102
Maximum traction efficiency obtained (10-15% wheel slip)	102
Overpowered tractor not used	102
Do not cultivate in poor conditions	20
Energy/fuel source (Buildings)	15
Energy/fuel source (Machinery)	14
Energy/fuel source (Production of inorganic N fertiliser)	13
Type of inorganic fertiliser	13
Nitrification inhibitors used	12
Rainfall forecasting used	12
Soil Nitrogen Supply (SNS) known	12
Energy/fuel source (Production of pesticides)	11
Pesticide sprayer equipment	11
Avoid unnecessary hose on irrigation reel	10
Cultivated land field not entered with heavy machinery when wet	10
Irrigation pump operating efficiently	10
Irrigation type	10
Irrigation water source	10
Ploughing depth	10
Soil aerator used on compacted areas (cultivated land)	10
Type of sub-soiling	10
Types of harrow	10
Manure application technique	9
Manure application timing	9
Slurry application technique	9
Slurry application timing	9
Slurry incorporation technique	9
Types of disc	9
Types of drill	6
Correct siting and accurate temperature sensors	5
Enclosed creep, heater lamp automatic control and dimmer switches	5
Ensure insulation always dry	5
Fans interlinked to heaters (heaters on only when fans low)	5
Insulated enclosed creep	5
Lying area panels on flat decks	5
Pig housing - Low energy lighting	5
Pig housing ventilation - Fan and ventilation functioning optimally and openings checked frequently for obstructions	5

Variable modifiers	Number of components
Pig housing ventilation - Flat deck with correct number of fans	5
Pig manure store	5
Pig slurry store	5
Pig slurry temperature	5
Straw chopping	5
Under floor heating, heated pads	5
Dairy cow diet	4
Beef cattle diet	3
Sheep diet	3
Correct thermostat setting and regular checks for leaks	2
Heat recovery system to recycle heat removed from milk to heat wash water	2
Vacuum pump with variable speed controls	2
Accurate milk tank thermostat	1
Accurate temperature sensors (ambient storage)	1
Accurate temperature sensors (refrigerated storage)	1
Air curtains / flexible doors	1
Automatic control system compared to manual control	1
Automatic lighting controls	1
Avoid product heating	1
Beef cattle manure store	1
Boilers and warm air heaters regularly serviced	1
Capacity control of the compressor in refrigeration (for when operating at reduced load)	1
Dairy cow dietary additives used	1
Dairy cow improved breed	1
Dairy manure store	1
Dairy slurry store	1
Dairy slurry temperature	1
Direct expansion refrigeration bulk tank	1
Electronic expansion valve used in refrigeration (instead of mechanical)	1
Evaporator defrosting used in refrigeration	1
Extra 50 mm polyurethane insulation	1
Feeding troughs moved frequently	1
Grassland not entered with heavy machinery when wet	1
Greenhouse boiler with flue damper	1
Greenhouse heating system	1
Greenhouse humidity set point at 90%	1
Greenhouse lighting set point on below 250 Wm-2	1
Greenhouse temperature set point decreased by 1C	1
Greenhouse thermal screens	1
Greenhouse windbreak	1
Improve store sealing at doors, eaves and vents (ambient storage)	1
Improve store sealing at doors, eaves and vents (refrigerated storage)	1
Improved milk tank and pipe insulation	1
Increase insulation thickness by 25 mm	1
Line switched off during breaks	1
Low energy lighting	1
Maximise heat transfer coefficient of compressor	1
Number of years plastic mulch is used	1
Number of years plastic on polytunnels is used	1
Only heat during occupancy	1
Pre-cool milk before storage tank	1
Pre-cool using ambient air ventilation	1
Process and line speed optimal	1
Recirculate warm air	1
Recycle process heat	1
Reduce area heated	1
Refrigeration condenser sufficiently ventilated	1

Variable modifiers	Number of components
Reset time clock after pull-down	1
Sheep manure store	1
Soil aerator used on compacted areas (grassland)	1
Substrate type	1
Thermostats checked against a thermometer	1
Types of mower	1
Types of rake	1
Use air curtains / flexible doors	1
Use ambient pre-cooling	1
Use forced ventilation	1
Use intermittent air circulation	1
Use low-pressure fan unit (compared to grain store specification fan)	1
Wash system	1

Table 3.6.1 shows how some modifiers are very specific being only linked to a single component (and probably single enterprise), whereas other modifiers are generic to a range of components and consequently enterprises. Those at the top of Table 3.6.1 in theory have potential for widespread adoption due their generic nature. Those at the bottom are restricted to specific farm components and enterprises, so by their very nature their potential for widespread adoption across the whole agricultural industry is limited, but this is not to say they could not be broadly adopted within the sector to which they apply. However, what still needs to be determined is the potential mitigation that any of these options have to offer, what the overall reduction in emissions would be if they were adopted, and if there are any issues or barriers that would prevent their adoption (e.g. some of the practices at the top of the list may seem like they have potential for widespread adoption, but there may be significant economic barriers or other impacts that could prevent this). The IMPACCT Policy Assessment tool can be used to help answer these questions.

It is beyond the scope of this project to examine every single potential mitigation option applied across the whole of Europe, or even a single Member State. However, a number of examples are presented below to illustrate process and also test the Policy Assessment tool. It should also be noted that the examples below are not for advocating the adoption of any particularly policy – they are simply for demonstrating the analysis process.

Policy Assessment Example 1: Barley Production in EU27. Impact of ensuring all vehicles are serviced regularly

Note: This example is presented to demonstrate how the policy tool can be used to assess the impact of a change in numbers upon greenhouse gas emissions. It is entirely **hypothetical**.

Ensuring that vehicles are regularly serviced helps improve their fuel efficiency and thus reductions in greenhouse gas emissions. It is something has potential for widespread adoption as it is linked to 108 farm components (see Table 3.6.1).

A baseline scenario was created in the Policy Assessment tool where no vehicles are regularly serviced and a future scenario where they are. The data entered (see Table 3.6.2) are the total for the all EU27 countries drawn from the Eurostat 2008 figures. Data has been split between the different modifiers on an equal basis, as the actual split is unknown. Similarly, data for areas rolled, harrowed, etc. have been assumed to be equal to the total area of barley production. The actual areas that undergo these operations may not match the total, but this information is not known. The amount of nitrogen applied has been based on a single value of 120kgN/ha.

Table 3.6.2: Data for barley production in the EU27

Fixed Modifiers		Data items								
Archaeological features	Soil type 1	Area of barley harvested (ha)	Tonnes of barley harvested (tonne)	Area of barley to which inorganic fertiliser is applied (ha)	Amount of nitrogen applied to barley (t)	Area of barley sprayed with pesticides (liquids) (ha)	Area discing (barley) (ha)	Area harrowed (barley) (ha)	Area ploughed (barley) (ha)	Area rolled (barley) (ha)
No archaeological features	Sand	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
No archaeological features	Loam	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
No archaeological features	Clay	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Some archaeological features	Sand	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Some archaeological features	Loam	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Some archaeological features	Clay	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Scheduled monument or equivalent	Sand	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Scheduled monument or equivalent	Loam	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889
Scheduled monument or equivalent	Clay	1604889	7232889	1604889	192587	1604889	1604889	1604889	1604889	1604889

The results that arise from this data are shown in Table 3.6.3. There are no sequestration impacts and there is no change in other impacts (in this instance the other impacts are associated ploughing, for which the practices have not changed). The emissions have decreased by 467426 tonnes CO_2e, which is an 11.1% drop from the baseline value. However, when compared to the normalisation factors this decrease is only 0.64% of combustion emissions from agriculture, 0.1% of total agricultural emissions and 0.01% of all emissions in the EU27.

Table 3.6.3: Impact of regularly servicing vehicles used in barley production across the EU27

	tCO2	tCH4	tN2O	tCO2e	tCO2 Sequestration	Other impacts	Data quality
Baseline				6264744		Potential negative impact on archaeological sites and features	
Future				5621048		Potential negative impact on archaeological sites and features	
Change	0	0	0	-643696			
% Change				-10.3%			
% of Total greenhouse gas emissions from agriculture in EU27 (2007)				-0.14%			
% of Total greenhouse gas emissions EU27 (2007)				-0.01%			
% of Fuel combustion from agriculture EU27 (2007)				-0.88%			

It should be noted that the baseline is where no vehicles are serviced regularly, whereas in reality a certain percentage of vehicles will already be serviced regularly, and therefore the difference between the baseline and future scenario is likely to be lower, more so if less than 100% of vehicles are serviced regularly. Additionally, the actual reduction potential depends on all the other practices are currently or could be adopted that will contribute towards reducing emissions, e.g. using the correct tyres and tyre pressures. Regularly servicing vehicles will reduce emissions by X% of the total emissions, thus a greater reduction is achieved when other practices are poor, whereas if other practices are better the potential reduction from regularly servicing vehicles will be lower. So ranging from best to worst case the potential reduction ranges from 4.8% to 10.3%.

There do not appear to be any barriers to the implementing this practice. The costs of regularly servicing vehicles should generally always be less than the costs of not regularly servicing (i.e. the cost of repairs and the impact on businesses from the loss vehicles at inconvenient times).

Policy Assessment Example 2: Dairy slurry management in EU27. Impact of increasing the use Anaerobic Digestion for Dairy Slurry

Note: This example is presented to demonstrate how the policy tool can be used to assess the impact of a change in practices upon greenhouse gas emissions and also where there synergistic benefits with other impacts. It is entirely **hypothetical**.

Anaerobic digestion has the potential to reduce greenhouse gas emissions from the storage of dairy slurry. There are 25 million dairy cattle in the EU 27 (Eurostat, 2009), the slurry of which will be stored in a variety of different ways, including those techniques included within the IMPACCT core database. Data for the current (baseline) situation have not been identified, so have been hypothetically allocated to those techniques within the IMPACCT database (see Table 3.6.4), i.e. a small amount of anaerobic digestion, then a large amount of uncovered lagoons and the remainder spread over the other techniques. For the purposes of this example, the amount of anaerobic digestion has been increased to cover just over 60% of dairy cattle, with a corresponding drop in the other storage techniques. The example below is also based on dairy cattle being housed for 20% of the year (which determines the amount of manure collected and stored, and consequent emissions), which may be variable depending on the location in Europe and systems being used, but in this instance a flat rate has been used.

Table 3.6.4: Data for dairy livestock in the EU27

Modifiers	Data items			
	Number of dairy cattle		Percentage of year dairy cattle are housed	
Dairy slurry store	Baseline	Future	Baseline	Future
Uncovered anaerobic lagoon	14500000	5000000	20	20
Anaerobic digestion	500000	15000000	20	20
Liquid/Slurry with natural crust cover	2500000	1250000	20	20
Liquid/Slurry without natural crust cover	2500000	1250000	20	20
Liquid Aerobic treatment - natural aeration	2500000	1250000	20	20
Liquid Aerobic treatment - forced aeration	2500000	1250000	20	20

The results of this change are shown in Table 3.6.5.

Table 3.6.5: Impact of increasing anaerobic digestion of dairy slurry across the EU27

	tCO2	tCH4	tN2O	tCO2e	tCO2 Sequestration	Other impacts	Data quality
Baseline	0	763180	6545.6	21030088.8	0	Potential negative impact on air quality	
Future	0	274175	2906.5	7720512	0	Potential negative impact on air quality	
Change	0	-489005	-3639.1	-13309576.8	0	Potential improvements to air quality	
% Change		-64.10%	-55.60%	-63.30%			
% of Total greenhouse gas emissions from agriculture in EU27 (2007)				-2.88%			
% of Total emissions from manure management EU27 (2007)				-15.19%			

As Table 3.6.5 shows, the use of anaerobic digestion for 60% of dairy cattle slurry has the potential to reduce total agricultural emissions by 2.88%, and to reduce emissions from manure management by 15.19%. This demonstrates that anaerobic digestion could be a significant mitigation option. Additionally, there appear to some synergistic benefits with respect to improvements to air quality. However, there are some significant capital-costs involved in deploying anaerobic digestion as an option to mitigate emissions which will present a significant barrier to adoption, unless capital grants are made available to farms to build the necessary infrastructure. Additionally, it should also be noted that the methane gathered from biogas plants will ultimately be used as a fuel which when combusted will release CO_2 emissions. Consideration should also be given to the fate the anaerobic digestate, which when used as a soil conditioner may result in some carbon sequestration and also some emissions during application. Therefore although the overall benefit of using anaerobic digestion is probably positive (with respect to reducing emissions) it is a little more complicated than outlined in the example above.

Policy Assessment Example 3: Manure management in EU27. Impact of increasing the use unconfined stacks and heaps

Note: This example is presented to demonstrate how the policy tool can be used to identify other potential negative impacts (i.e. trade-offs). It is entirely **hypothetical**.

The IMPACCT software often highlights that changing the manure store to 'Solid storage (unconfined piles or stacks)' is a potential mitigation option. Table 3.6.6 shows some hypothetical data for manure management practices for the 25 million head of dairy cattle in the EU27 (data for the actual practices are unknown). In this instance there are more modifiers than the previous examples, illustrating the complexity of the issue (note: to reduce the size of the table, rows where data are zero have been removed). A range of different manure management practices have been defined in the baseline scenario and these have been decreased in the future scenario with a corresponding increase in 'Solid storage (unconfined piles or stacks)'.

Table 3.6.6: Hypothetical data for dairy manure management in the EU27

Modifiers				Data items			
				Number of dairy cattle		% of year dairy cattle are housed	
Location	Dairy manure store	Dairy manure temperature	Distance between dairy manure stores and surface water or drains	Baseline	Future	Baseline	Future
Northern Europe	Solid storage (unconfined piles or stacks)	Unknown	Greater than 10 metres	2500000	7900000	20	20
Northern Europe	Solid storage (unconfined piles or stacks)	Unknown	Less than 10 metres	500000	1250000	20	20
Northern Europe	Deep bedding - no mixing (stored for >1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Northern Europe	Deep bedding - no mixing (stored for >1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Northern Europe	Deep bedding - active mixing (stored for >1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Northern Europe	Deep bedding - active mixing (stored for >1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Northern Europe	Deep bedding - no mixing (stored for <1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Northern Europe	Deep bedding - no mixing (stored for <1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Northern Europe	Deep bedding - active mixing (stored for <1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Northern Europe	Deep bedding - active mixing (stored for <1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Northern Europe	Composting - static pile (forced aeration)	Unknown	Greater than 10 metres	500000	0	20	0
Northern Europe	Composting - intensive windrow (regular turning for mixing and aeration)	Unknown	Greater than 10 metres	1000000	500000	20	20
Northern Europe	Composting - intensive windrow (regular turning for mixing and aeration)	Unknown	Less than 10 metres	500000	0	20	0
Northern Europe	Composting - passive windrow (irregular turning for mixing and aeration)	Unknown	Greater than 10 metres	2000000	500000	20	20
Northern Europe	Composting - passive windrow (irregular turning for mixing and aeration)	Unknown	Less than 10 metres	500000	500000	20	20
Southern Europe	Solid storage (unconfined piles or stacks)	Unknown	Greater than 10 metres	2500000	7500000	20	20
Southern Europe	Solid storage (unconfined piles or stacks)	Unknown	Less than 10 metres	500000	1000000	20	20
Southern Europe	Deep bedding - no mixing (stored for >1 month)	Unknown	Greater than 10 metres	1000000	0	20	0
Southern Europe	Deep bedding - no mixing (stored for >1 month)	Unknown	Less than 10 metres	500000	0	20	0
Southern Europe	Deep bedding - active mixing (stored for >1 month)	Unknown	Greater than 10 metres	1000000	0	20	0
Southern Europe	Deep bedding - active mixing (stored for >1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Southern Europe	Deep bedding - no mixing (stored for <1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Southern Europe	Deep bedding - no mixing (stored for <1 month)	Unknown	Less than 10 metres	500000	250000	20	20
Southern Europe	Deep bedding - active mixing (stored for <1 month)	Unknown	Greater than 10 metres	1000000	500000	20	20
Southern Europe	Deep bedding - active mixing (stored for <1 month)	Unknown	Less than 10 metres	500000	350000	20	20
Southern Europe	Composting - intensive windrow (regular turning for mixing and aeration)	Unknown	Greater than 10 metres	500000	500000	20	20

Modifiers				Data items			
				Number of dairy cattle		% of year dairy cattle are housed	
Location	Dairy manure store	Dairy manure temperature	Distance between dairy manure stores and surface water or drains	Baseline	Future	Baseline	Future
Southern Europe	Composting - intensive windrow (regular turning for mixing and aeration)	Unknown	Less than 10 metres	500000	0	20	0
Southern Europe	Composting - passive windrow (irregular turning for mixing and aeration)	Unknown	Greater than 10 metres	1000000	500000	20	20
Southern Europe	Composting - passive windrow (irregular turning for mixing and aeration)	Unknown	Less than 10 metres	500000	0	20	0

The impact of this change in manure management practices is shown in Table 3.6.7.

Table 3.6.7: Impact of increasing Solid storage (unconfined piles or stacks) of dairy manure across the EU27

	tCO2	tCH4	tN2O	tCO2e	tCO2 Sequestration	Other impacts	Data quality
Baseline	0	135976	40804	15558992	0	Potential negative impact on surface water quality	
Future	0	83638.6	22577.5	8819060	0	Potential negative impact on surface water quality	
Change	0	-52337.4	-18226.5	-6739932	0	Potential decrease in surface water quality	
% Change		-38.5%	-44.7%	-43.3%			
% of Total greenhouse gas emissions from agriculture in EU27 (2007)				-1.46%			
% of Total emissions from manure management EU27 (2007)				-7.69%			

Table 3.6.7 shows that the shift towards greater use of Solid storage (unconfined piles or stacks) has resulting in the expected decrease in emissions, with a 1.46% reduction in total greenhouse gas emissions from agriculture and 7.69% decrease in emissions from manure management. However, Table 3.6.7 also shows that there is a potential decrease in surface water quality. This because in the data defined in Table 3.6.6, some of the manure stores are located within 10 metres of surface water, and the shift to a less confined (more open) form of manure storage could increase the risk of the loss of effluent and nutrients from those stores into surface water. In the UK, the locating of manure stacks within 10 metres of surface water would be a breach of regulations (and this may be the case in other member states), so it's possible that this potential risk could be mitigated through the enforcement of other regulations. However, the purpose of this example is to illustrate that there may be other consequences and impacts as a consequence of actions for emissions mitigation, that could potentially be a barrier to it adoption.

3.6.4. Appraisal of the IMPACCT policy assessment tool

The Policy Assessment tool, in combination with searching the core database, has proved be useful for some policy analysis. The 3 example provided above are relatively simple, and are hypothetical, but they demonstrate the process that can be undertaken. However, there are some difficulties to be overcome, some of which are common to any form of policy analysis.

Firstly, defining the baseline scenario can be very difficult. Defining the 'current' situation involves undertaking significant research into the statistics that are available and in many instances may even require new research, especially with respect to establishing current practices and/or distribution of those practices.

Secondly, related to the baseline scenario, should we wish to assess a more complex policy, e.g. where multiple practices are changing, the number of combinations (of modifiers) for which data need to be sought can quite significant. In example 3 above, there are 144 combinations for which baseline a future data need to be entered (although it is possible to leave some blank if they are not applicable), and this is just a change in a single farm practice. If more practices were to be added the combinations could easily exceed several thousand or more.

At the moment, the IMPACCT software allows the user to create two types of project, practice-based or numbers only. The practice-based project allows the user to alter numbers in both the baseline and future scenarios, but the data items they can alter are fixed by the practices that are changed (i.e. they are not free to select any data item, like a numbers only project). Consequently, there may be instances when the user wishes to alter the practices and also change unrelated numbers, but this is not possible at the moment. What is required is a combined type of project where the user is free to select both changes in practices and numbers. This is not considered to be a major problem, but is something that could be developed in the future if needed.

Finally, the IMPACCT policy tool has been developed with limited time and resources and so has sought to utilise the same interfaces (where possible) as those developed for the farm assessment tool. Although this works quite well, it is not ideal and in some instances not very intuitive. For example, when using the farm assessment wizard to create the baseline and future scenarios, the user is asked to enter numbers and also run the calculation, but these numbers and results are not used with the actual policy assessment, where the user enters more data and undertakes another calculation. The data and calculation steps within the farm assessment wizard are necessary in order for the policy assessment to compare the baseline and future scenarios, to determine the differences and thus what policy to implement/calculate, but this is not obvious to the user. Ideally what is needed are bespoke interfaces, for the policy assessment tool, that allow the user to select changes in practices and numbers – this would simplify the process.

3.7. Task 6: Proofing the model

Activity Start Date	M3, M7	Activity Finish Date	M4, M10
Milestones and Deliverables			
Key project partners involved	University of Hertfordshire & subcontractors		

The objective of this task was to test the model constructed in Task 4 in order to assess its performance and make any amendments to further refine it. It is an investigative process that seeks to identify information about the quality of the developed software and its capabilities. The process of validating and verifying the software helps to demonstrate that it:

- Meets the specification 'blueprint' as developed in Activity 4.1 (see Section 3.5.1);
- That it works as expected providing the correct results and
- It is useable, functional and practical.

There were two stages to the 'tentative' model testing. Firstly, the model was tested in house and secondly it was distributed for beta testing. Beta-testing was carried out on farm as the Phase 2 case studies and with other interested parties.

3.7.1. Activity 6.1. In-house testing

As described in previous sections of this report the 'tentative' model has been developed in discrete modules. As each module has been completed it has been subject to a first phase of rigorous in-house testing and proofing by the project main contractor. This testing process aimed to ensure that all the major bugs and errors were resolved before being distributed for beta-testing (Activity 6.2). The in-house testing included the following activities:

1. **Functional testing**: Testing the software with sample data to cover a range of conditions under which it will be used. The objective here was to detect and correct any major defects that prevent the software from correctly functioning.
2. **Validity testing:** The software was tested with known input and output data to check that the correct data is being retrieved from the core database, that it is being processed correctly and that any calculations made are correct. This included ensuring that the system can handle the data input in various standard formats such as, for example, ###.## and ###,##.
3. **Specification comparison:** A number of software testers were used to compare the functionality and facilities offered by the model with that within the specification 'blueprint' as developed in Activity 4.1 (see Section 3.5.1).
4. **Hypothetical case studies:** A number of theoretical case studies have been run through the model. Data for these case studies has been drawn from previous projects but are based on actual farm data. This testing process was an additional check on the validity of the model and tested how well the model performs with respect to providing 'sensible' results. This enabled any final refinements to be made prior to sending out the model for testing in the phase 2 case studies.

3.7.2. Activity 6.2. Case Studies Phase 2

The Phase 2 case studies were undertaken in 7 EU countries and were undertaken by the sub-contractors. Each farm was visited twice. The first visit (as described in Task 4, see Section 3.5.1) introduced the concept of the tool and obtain feedback to steer the model development and so inform the specification blueprint . The second visit involved beta-testing a prototype of the model that was developed in Task 4 on the farm.

The purpose of these case studies was to provide an objective, independent view of the software and so each subcontractor was asked to provide the following information:

- Descriptions of the farms visited including the farm activities and processes;
- The IMPACCT data files for the farms created during the farm visit. This was to enable any bugs to be easily identified and to allow the case studies to be recreated;
- General comments and feedback on how useful farmers and growers found the software to be;
- Any issues associated with data entry. For example: How easy was data entry? How could it be improved? Was the data required readily available?
- Feedback on the reporting. For example: Are the reports useful? Is there any extra information or data that could be shown that would be helpful to the farmer? Is the layout of the reports understandable / acceptable? If not, how could they be improved?
- Feedback on any other comments on the general functionality of the software, for example, Were there any issues with navigation, file saving, printing, etc?
- Feedback on any suggestions or ideas for future improvements;
- Feedback regarding any bugs or errors that occurred when using the software.

Table 3.7.1 provides a summary of the farms on which the Phase 2 case studies were carried out and Table 3.7.2 provides a summary of the feedback. Detailed input data and results for each of the case studies can be found in Appendix A.

Table 3.7.1: Details of phase 2 case study farms

Member State	Case Study Name	Activities & Processes
France	Leudeville	465 ha dairy farm with cropping.
	Iffendic	127 ha dairy farm with cropping for animal feed.
	La Touche Rolland, Talensac	62 ha dairy farm with cropping for animal feed.
Germany	EAG Borna, Liebschützberg	965 ha mixed farm with cereals, maize, beet, dairy, beef and pork enterprises.
	Gut Markee, Brandenburg	1020 ha arable farm growing winter rape, wheat, barley, rye, triticale and corn
Hungary	Hatvan	5 ha horticultural holding growing a variety of crops including green paprika, tomato, beans and strawberries plus a small area of wheat and maize.
	Gödöllő, Szárítópuszta	37 ha arable farm.
	Agrár-Béta, Birkamajor	2100 ha arable farm growing a variety of cereals, legumes and oil seed crops.
	Lovasberény	1800 ha cereal farm with some livestock (cattle and pigs)
	Karcsa	31 ha cereals including wheat, maize, barley, rape, and sunflower

Member State	Case Study Name	Activities & Processes
Italy	Via Abbazia, Campagnola Emilia	200 ha pig farm.
	Ghiardo Di Bibbiano, Reggio Emilia	270 ha dairy farm.
Poland	Wisznia Mala, Wroclaw	170 ha Arable farm growing barley, wheat, OSR and Potatoes.
	Ligota Piekna	70 ha Arable farm growing a variety of cereals and OSR.
	Rogozo	250 ha arable farm growing wheat, triticale, OSR, maize and potatoes.
	Strseszow	440 ha cattle farm with some cropping for animal feed.
Slovenia	Šetarova, Lenart V Sloven skih Goricah	840 ha beef farm with cropping for animal feed
	Martjanci	270 ha mixed farm with a variety of arable and cattle enterprises.
	Bloke	46 ha cattle and grassland farm.
United Kingdom	Drumdow, Stranraer	202 ha livestock farm with beef, sheep and some barley.
	Viewfield, Castle Douglas	971 ha livestock farm with beef, sheep and pigs

Feedback was provided on forms designed for the purpose. However, reports on run-time bugs were addressed immediately and a version of the software released so that the case studies could continue. Details of the feedback is given in Table 3.7.2, however these are briefly summarised below:

- Generally most people were happy with the software and its design. In particular the use of charts and icons to summarise the data was appreciated.
- Most comments were concerned about the restrictions in the options available. For example, only a modest range of livestock diets are available and data for individual breeds was not included. Whilst it is acknowledged that this would be valuable, it has not been possible to include all possible options in such a short project with restrictions on the resources available. Such detailed data is not available in the literature and many of the options requested would require specific modelling exercises to be undertaken.
- Another issue was that some inputs required, such as soil type, fertiliser / pesticide types vary from field to field but data is requested at farm level. This is acknowledged as an issue but using the system at field level would require another level of input data and reporting detail which would significantly complicate the software. In addition it would also mean that the time to complete the calculations would also increase significantly. However, the there is nothing to stop an end user just looking at a small part of their farm such as a single field or group of fields rather than the whole farm all in one go.
- Several farmers commented that if they themselves were to be asked to use the system then it should be translated into different languages.

Table 3.7.2: Software piloting feedback

Issue & Comments	How tackled
General	
Improved description of components and what they included was needed.	These comments were mainly down to the lack of language translation. Ideally a help button should be included and this translated but time has not allowed this.
Some farmers reported that the literature data on fuel usage per operation does not match what they use. This results in much higher emissions that are actually occurring.	This is an interesting note in itself. The figures for fuel/energy use and associated emissions in the core database are responsive to different practices, but there are also fairly general, so there are likely to be specific instances where a farms actual fuel use is notably different.
More information on what the icons and 'bar' ratings required.	A key is provided, but this could improved, especially if links to further information were implemented (see Section 3.6.3)
Limited information regarding sequestration seems to be available.	This is a reflection of the amount of data available.
Scope and depth	
Some information appears too generalised (e.g. some UK cattle consume up to 20% less than continental breeds (e.g. Angus & Luing) but no account of that is taken in the calculations.	This is a reflection of the amount of data available.
Farmers unsure if the energy value of the product is taken into account off the farm i.e. the whole story from grass to plate should be considered.	The software is only farm-gate at the moment. Impacts beyond the farm gate would require detailed information on what happens to the produce once it leaves the farm. This is possible to do, but is beyond the scope of this project and would also significantly add to the data input requirements of the model.
System current requests one soil type per farm whilst it may vary between fields. Similarly on one type of fertiliser for the farm can be selected whilst this may also vary between fields.	This is due to the resolution of the model. This would add another layer of complication and require data at field level. Beyond the scope of the current project.
Issues were raised regarding the range of livestock diets available. Those for dairy cows did not seem to be suitable for Poland and similar restrictions were a problem for beef diets in Scotland	This problem is due to the huge number of different diets available. It's not been possible with the available resources to model them all. It is hoped that more can be added in the future.
Harrow & ploughing choices not broad enough.	Acknowledged
Options available do not cope for the use of contractors when the farm itself does not won heavy equipment.	The data should be entered regardless of whether a contractor does the work or not.
Cattle types should be sub-divided to show for example sucklers and followers.	We did originally plan to use such a breakdown, but emissions data were lacking such detail so this could not be implemented.
Some countries have a very high diversity of landscape features and soil types, and it is therefore hard to put into the model just one generalised type.	Acknowledged
Age of machinery does not seem to be taken in to account.	The age is taken into account in some

Issue & Comments	How tackled
	modifiers for some practices, but not all.
Functionality	
Sometimes mouse, return key, arrow keys behave different when being used for the same function such as selecting options.	Bug corrected
Data Input	
Some option boxes cannot be unselected once selected.	Misunderstanding about how software works.
Needs more checking on data inputting as characters are permitted in numerical fields.	Bug corrected
Inputting quantities screen can be a little confusing regarding what is actually being requested and the units.	Some amendments & redesign have been implemented.
Comments were made on the amount and detail of data required.	This has been streamlined and simplified as much as possible but it's not possible to reduce it further without losing resolution, accuracy or usefulness.
More options should be listed to cover specific demands of diverse EU agricultural practices.	Acknowledged. Requires more data to be entered into the core database
Data on pesticides requires quantities of active substances – some farmers had trouble making these calculations. Similarly pesticide was entered as liquid but information requested subsequently was for weight of active substance.	Problem is appreciated but beyond the scope of this project to do it effectively.
Reporting	
No option currently of saving a whole report or opening a saved one.	Option now available
Need to keep the headings at the top of each reporting table.	Not easy to fix due to limitations of HTML.
Overview rather 'dry' and takes a while to absorb all the information.	Acknowledged (could be improved with links to further information – see Section 3.6.3)
The overall carbon balance for the farm (i.e. emissions minus sequestration) is not presented.	The data for carbon sequestration is limited within the database, is often uncertain and only applies for limited time until equilibrium is reached and there are also arguments that emissions should not be offset against sequestration. Therefore this is not automatically done with the software, but the data is presented to the user so that they can calculate a balance themselves.
Overview chart – colours are confusing (e.g. sheep and environmental features are both yellow whilst inorganic fertiliser and seedbed are both bright green)	Acknowledged: It is a limitation of software controls used (colours are allocated automatically by the software)
A great deal of information is given which takes a long time to assess.	Acknowledged
Possible Improvements	
On large farms with many activities the software is quite slow to run it would be helpful to be able to save output files for reviewing to save having to re-run.	Implemented.
Emissions produced by the farmer and the producer should be separated	Beyond the scope of this project
The ability to benchmark against typical &/or other farms of the same type would be valuable.	Beyond the scope of this project
Comments on usefulness	
Generally the design and reporting procedures were well liked especially the use of icons and charts.	
Worries from some sources that this package could be used by the EU to charge a levy for any emissions beyond a threshold value.	
Concerns that different carbon calculating systems give different answers. Whilst there are reasonable explanations	

Issue & Comments	How tackled
for this such as the methods used, data replied upon and what is and is not included, it was widely felt that these differences (which can be significant) could cause a lack of faith in the packages and methods generally.	
Some farmers think the management of a farm is too complex problem for a simple model. The right decisions are not fixed in time and space and a capable land manager must always adapt the technological solutions according to constantly changing circumstances (e.g. weather, energy, consumables prices, and prices of agricultural produce)	
Farmers had trouble interpreting the emissions results and whether or not they were good or bad for a particular farm type.	
The software was generally easy to follow and to enter data.	
Model was a little restrictive due to the range of options available.	
Most of the farmers involved in the case studies felt that the system should be translated into other languages.	

Key:

Beyond project scope	*Data/software limitation*	*Fixed or implemented*	*Comment only*

3.7.3. Activity 6.3. Refining and polishing the model

The findings and end user feedback from the case studies was used to refine the model as best as good be done within the time available. This included the amendments and bug fixes shown in Table 3.7.2 above. Once the major operational bugs had been corrected the software was made available to other interested parties.

3.7.4. Appraisal of the IMPACCT farm assessment tool

Generally the IMPACCT farm assessment tool has proved to be valuable means by which to identify the key sources and sinks of greenhouse gases on the farm and potential mitigation options. Importantly, the mitigation options are presented within the context of any other impacts and any economic information available, thus allowing the user to identify win-win situations or where there may be trade-offs between other or economic impacts.

The results displayed are undoubtedly a little 'raw', i.e. a lot of data and not enough guidance and interpretation. This is something that has principally been limited by the time that was available to develop the software. There is scope to make improvements here, for example as described in Section 3.6.3, it would be fairly easy to provide links to further information and resources.

In relation to the previous point, it would also be useful for users to be able to compare their results against industry benchmarks or similar farms, in order for them to be able to place their performance with respect to emissions in context. Clearly, this would be dependent on benchmark data being available, but there is scope to do this within the software with a few minor amendments, e.g. where emissions are expressed per head of livestock or tonne of product. There are normalisation factors available within the policy tool, which can be regarded as benchmarks, but these would probably be meaningless for an individual farm, e.g. comparing the emissions of a farm to the entire emissions for the whole of Europe, or even an individual country, would not reveal much as it is such a broad measure. So it's a question of whether such factors could be disaggregated to the extent where they are meaningful at the farm level.

4.0. Administrative Issues

The project contract included a number of milestones by which progress would be measured. These are shown in Table x and all milestones were reached according to the project timetable and Schedule.

The milestones below indicate key points in the work at work where progress and quality can be assessed, where important decisions may need to be made. Five milestones have been identified (M1-M5) and these are given in Table 4.1 below.

Table 4.1: List of milestones

Number	TASK	Description	Date reached
M1	1	Breakdown of farm types by component	Jan 2010
M2	2	Completion of consultation exercises & phase 1 Case Studies	Feb 2010
M3	3	Environmental trade-off data identified	Mar 2010
M4	4	Beta version of the model	June 2010
M5	6	Final version of the model	Sept 2010

Additionally, a number of 'deliverables' were identified, as shown in Table 4.2. These were also submitted according to the project schedule.

Table 4.2: List of deliverables

Number	Description	Date delivered
D1	Kick-off meeting & inception report	End month 1
D2	First interim report	End month 3
D3	Second interim report	End month 7
D4	Draft final report	End month 10
D5	Final report	End month 11
D6	'Tentative' model	End of project

The following key meetings were held:

- 30th November 2009, DG Environment, European Commission, Brussels. Kick-off meeting with EC Project officers to discuss the Inception report and the project objectives.
- 26th February 2010, DG Environment, European Commission, Brussels. Meeting with EC Project officers to discuss the first Interim Report and progress.
- 17th June 2010, DG Environment, European Commission, Brussels. Meeting with EC Project officers to discuss the second interim report and progress.
- 13th July 2010, EC Joint Research Centre, Ispra, Italy. Meeting with the EC Project officer and JRC staff to discuss the project and demonstrate the 'tentative' model.
- 22nd September 2010, DG Environment, European Commission, Brussels. Meeting with EC Project officers to discuss the draft Final report.

5.0. Discussion

Climate change as an environmental issue has risen high up the agenda in recent years and actions are being sort across all sectors to decrease atmospheric concentrations of greenhouse gases (and consequent climate change impacts), principally via reducing atmospheric emissions but also via sequestering carbon. This is a worthy goal, but it is important not to forget about all the other environmental issues and challenges that remain. The ultimate goal is to achieve a sustainable balance between environmental, social and economic objectives. The pursuit of any specific objective at the expense or exclusion of another is unlikely to result in a 'sustainable balance'. Therefore it is important to take a holistic and integrated perspective, in order to understand the synergies and trade-offs between objectives in order to identify those options that have the greatest potential to achieve the sustainable balance.

This project has adopted this perspective with respect to agriculture and the contribution it makes towards greenhouse gas emissions. Although the principle focus has been on greenhouse gas emissions and carbon sequestration with respect to quantifying effects, the project has aims to maintain an integrated approach by including information on other environmental and economic impacts, albeit in a more qualitative way.

It has undoubtedly been a very ambitious project to undertake within an 11 month period. A lot of work has been undertaken during this time, resulting in some detailed reports and the 'tentative' model – the IMPACCT software. In many respects this model has exceeded expectations. A number of comments were received from farmers and project partners to the effect that they were not expecting something quite so detailed, complex and advanced. However, it should also be remembered that the model is 'tentative' and very much a prototype and as such it does have some limitations:

- Firstly, the underlying data within the core database is very much a 'first edition' and does not cover all farming enterprises and practice variations. There is no doubt it is a very substantial database (being over 50MB in size and containing several hundred thousand records), but it could be improved and refined. More detailed 'meta-modelling' could be undertaken to improve some emission factors (and their data quality) and greater number of modifiers could be added to cover a greater spectrum of activities to better reflect the diversity of farming practices in different regions across Europe. There are also undoubtedly a few anomalies that need to be checked and verified. Efforts will be made beyond the life of this project to improve some of the data where possible and add in new data when it emerges, so that the IMPACCT tool is maintained, but it would benefit from additional funding to significantly review, revise, expand and improve the underlying data. There may also be some benefits from some restructuring of the core database itself. For example, at the moment some farm components have the same emissions data, e.g. emissions from ploughing are the same for wheat as they are for barley, but in order to allocate them to each crop the emissions data are duplicated for each component. This increases the size of database and possible impacts upon its performance, so this is undesirable. A potential solution would be to have a one set of emissions data that is common to multiple components (effectively aliasing a base set of data to two or more components). This would require some database restructuring and amendments to the software, but would result in easier administration of the core database and possibly improved software performance.
- Secondly, sequestration data are somewhat lacking compared to the amount of data on emissions. This is partly due to the amount of data that is generally available and the uncertainty associated with sequestration processes. In relation to this at the moment carbon sequestration is not presented to the

user as an option for mitigation emissions. A number of case study farmers commented that the balance should be calculated and net difference shown as the 'headline' figure for the farm. This has not been done partly because of the uncertainty in the data and also because the sequestration figures only apply for a limited time period until a carbon equilibrium has been reached, so it could be misleading to offset emissions with the sequestration figures. This also follows guidelines such as those laid out in PAS 2050 (BSI, 2008). However, there is still scope to improve the sequestration data within the core database and how this is used within the IMPACCT software.

- Thirdly, in relation to the core database, data and information on other environmental impacts could be improved. A number of 'other impacts' have been input into the core database, but they are very much a selection of impacts to demonstrate the process and not necessarily a comprehensive set. Additionally, at the moment all 'other impacts' are expressed using a simple scoring system, but there is potential scope to provide more quantitative data, in the same way as greenhouse gas emissions, for some impacts, for example losses of nitrate via leaching. This was beyond the scope of this project as it would involve additional meta-modelling, but it is something could be implemented with only some minor modifications to existing structure of the core database and the software interface.
- Fourthly, the economic data held in the core database was one of the more problematic data sets to gather as part of this project. The original plan was to gather and store economic data in the same way as emissions and other impacts and to present this information in the results alongside the emissions data. However, the economic data proved to be scarce and highly variable in format to the extent that it did not fit the structure of the model and an alternative solution was sought (i.e. the economic information is current attached to modifiers and data items). The core database is still structured to store economic data information in the same format as emissions data, so should economic data improve there may be scope to implement this approach in the future.
- Fifthly, the data quality score used within the model provides a good 'barometer' of the quality of the evidence that has been used as a basis for the calculations. However, this data quality score does not necessarily represent the uncertainty and variability. Some aspects, such as carbon sequestration, are currently uncertain and a range of values can exist for certain parameters. It will have been partly taken into account in the score but what should be done would be to include the range of data (e.g. from best to worse case) and store this within the core database and then allow the model to draw upon these figures to express a range within the end results.
- Finally, the IMPACCT software interface is also very much a prototype and could be improved. The general functionality and simplicity of the interface has been praised by those who have used it and most have it easy to use. However, some compromises were made to develop the software in a relatively short space of time, for example the reuse of interfaces designed for the farm assessment within the policy assessment. Additionally, the speed of the calculation and data processing routines are sometimes unacceptably slow, particularly when there are lot of farm components and mitigation options, so this is something that would need to be addressed in any future developments. Consideration should also be given to the potential to develop a web-based version. This would be a significant project to undertake with a number of technical challenges to overcome, but it is the future direction of many applications so would need to be considered in any future developments.

However, despite these limitations, the IMPACCT model has provided a 'step in the right direction'. In the case of the farm assessment, it focuses users towards those practices that likely to be most effective at reducing emissions and the cost benefit of those practices with respect to any likely economic impacts and other environmental impacts. This could be further enhanced with links to additional information (such as websites or other models) for specific practices to help users undertake a more detailed assessment of the implications implementing the mitigation options on their specific farm. As such the tool could become a powerful means of providing targeted advice and guidance as part of a knowledge transfer programme. In the case of the policy tool there is clear scope to draw upon data in the core database to help identify mitigation options that have potential for widespread adoption. The limitation with respect to defining baseline scenarios, but in relation to this the policy tool can also be used identify research requirements, i.e. if a particular change in practices has been identified as a potential mitigation option, then the IMPACCT policy assessment will identify what data needs to be known in order to calculate the likely reduction in emissions that could achieved for a given area, such as the EU.

References

AAFC - Agriculture and Agri-Food Canada (2002) *Statistics on income of farm families*, See http://www.statcan.gc.ca/pub/21-207-x/2006000/4069194-eng.htm.

Abad, M., Noguera, P., Puchades, R., Maquieira, A. and Noguera, V. (2002) Physico-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants. *Bioresource Technology*, **82**, 241-245.

Abberton, M.T., Marshall, A.H., Humphreys, M.W., Macduff, J.H. Collins, R.P. and Marley, C.L. (2008) Genetic Improvement of Forage Species to Reduce the Environmental Impact of Temperate Livestock Grazing Systems. *Advances in Agronomy*, **98**, 311-355.

ADAS (2007a) *Rationale for the proposed NVZ Action Programme measures*. ADAS report to Defra – supporting paper D4 for the consultation on implementation of the Nitrates Directive in England. July 2007.

ADAS (2007b) *Investigating the effectiveness of NVZ Action Programme measures: Development of a strategy for England*. Report for Defra Project WT03017. June 2007.

Alcock, D. and Hegarty, R.S. (2005) *Effects of pasture improvement on productivity, gross margin and methane emissions of grazing sheep enterprises*. In Second Int. Conf. on Greenhouse Gases and Animal Agriculture, Working Papers (eds C. R. Soliva, J. Takahashi and M. Kreuzer), 127–130. Zurich, Switzerland: ETH.

Alvarez-Lopez, C.J., Riveiro-Valino, J.A. and Marey-Perez, M.F. (2008) Typology, classification and characterization of farms for agricultural production planning, *Spanish Journal of Agricultural Research*, **6(1)**, 125-136.

Andersen, E., Elbersen, B., Godeschalk, F., and Verhoog, D. (2007) Farm management indicators and farm typologies as a basis for assessments in a changing policy environment. *Journal of Environmental Management*, **82(3)**, 353-362.

Andres, P. and Domene, X. (2005) Ecotoxicological and fertilizing effects dewatered, composted and dry sewage sludge on soil mesofauna: A TME experiment. *Ecotoxicology*, **14**, 545-557.

Aulakh, M. S., Wassman, R., Bueno, C., Kreuzwieser, J. and Rennenberg, H. (2001). Characterization of Root Exudates at Different Growth Stages of Ten Rice (Oryza sativa L.) Cultivars. *Plant Biology*, **3**, 139-148.

Banks, C.J., Salter, A.M. and Cheshire, M. (2007) Potential of anaerobic digestion for mitigation of greenhouse gas emissions and production of renewable energy from agriculture: barriers and incentives to widespread adoption in Europe. *Water Science and Technology*, **55**, 165-173.

Bareth, G., Heincke, M. and Glatzel, S. (2001) Soil-land-use-system approach to estimate nitrous oxide emissions from agricultural soils. *Nutrient Cycling in Agroecosystems*, **60**, 219–234.

Beauchemin, K. A., Kreuzer, M., O' Mara, F. and McAllister, T.A. (2008) Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*, **48**, 21-27.

Bending, G.D. and Turner, M.K. (2009) Incorporation of nitrogen from crop residues into light fraction organic matter in soils with contrasting management histories. *Biology and Fertility of Soils*, **45**(3), 281-287.

Benedict, M.R., Tolley, H.R., Elliott, F.F. and Taeuber, C. (1944) Need for a New Classification of Farms, *Journal of Farm Economics*, **26(4)**, 694-708.

Birkhofer, K., Wise, D.H. and Scheu, S. (2008) Subsidy from the detrital food web, but not microhabitat complexity, affects the role of generalist predators in an above-ground herbivore food web. Oikos, 117, 494-500.

Boag, B.L.F., Palmer, L.F., Neilson, R., Legg, R and Chambers, S.J. (1997) Distribution, prevalence and intensity of earthworm populations in arable land and grassland in Scotland. *Annals of Applied Biology*, **130**, 153-165.

Bousted, I. (2003) *Eco-profiles of the European plastics industry. Polyolefins.* The Association of Plastics Manufacturers in Europe (APME), Brussels, Belgium.

Bouwman, A.F. (1996) Direct emission of nitrous oxide from agricultural soils. *Nutrient Cycling in Agroecosystems*, **46**, 53-70.

Bradley, R.I., Milne, R., Bell, J., Lilly, A., Jordan, C. and Higgins, A. (2005) A soil carbon and land use database for the United Kingdom. *Soil Use and Management*, **21**, 363–369.

Brentrup, F., Küsters, J., Lammel, J. and Kuhlmann, H. (2002) Impact assessment of abiotic resource consumption conceptual considerations. *The International Journal of Life Cycle Assessment*, **7**(5), 301-307.

Brentrup, F., Küsters, J., Kuhlmann, H. and Lammel, J. (2004) Environmental impact assessment of agricultural production systems using the life cycle assessment methodology I. Theoretical concept of a LCA method tailored to crop production. *European Journal of Agronomy*, **20**, 247–264.

Brentrup, F. and Pallière, C. (2008) Greenhouse gas emissions and energy efficiency in European nitrogen fertiliser production and use. *The International Fertiliser Society Proceedings*, 639.

Briggeman, B.C., Gray, A.W., Morehart, M.J., Baker, T.G. and Wilson, C.A. (2007) A new US farm household typology: Implications for agricultural policy*, Review of Agricultural Economics*, **29(4)**, 765-782.

Brooker, R. and Young, J. (Editors) (2005) *Climate change and biodiversity in Europe: a review of impacts, policy, gaps in knowledge and barriers to the exchange of information between scientists and policy makers*. NERC Centre For Ecology And Hydrology, Banchory Research Station, UK.

Brown, L., Syed, B., Jarvis, S.C., Sneath, R.W., Phillips, V.R., Goulding, K.W.T. and Lie, C., (2002) Development and application of a mechanistic model to estimate emission of nitrous oxide from UK agriculture. *Atmospheric Environment*, **36**, 917–928.

BSI (2008) PAS 2050:2008. *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. Publicly Available Specification*. British Standards Institute, Carbon Trust, Department for Environment, Food and Rural Affairs (Defra). ISBN 978 0 580 50978 0.

CALU - Centre for Alternative Land Use (2007) *Managing Energy and Carbon. The farmer's guide to energy audits*. University of Bangor, Wales. www.calu.bangor.ac.uk.

Campbell, C.A., Zentner, R.P., Janzen, H.H. and Bowren, K.E. (1990) *Crop Rotation Studies on the Canadian Prairies*. Publ. 1841/E. Res. Br., Agric. Canada, Can. Govt. Publ. Ctr., Ottawa, ON, 133.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M. and Ullyett, J.M. (2008) Countryside

Survey: UK Results from 2007. NERC/Centre for Ecology & Hydrology, 105pp. CEH Project Number: C03259.

Caserini, S., Livio, S., Giugliano, M., Grosso, M. and Rigamonti, L. (2010) LCA of domestic and centralized biomass combustion: The case of Lombardy (Italy). *Biomass and Bioenergy*, **34**(4), 474-482.

Cerri, C.C., Bernoux, M., Cerri, C.E P. and Feller, C. (2004) Carbon cycling and sequestration opportunities in South America: the case of Brazil. *Soil Use Management*, **20**, 248–254.

Chadwick, D.R. and Pain, B.F. (1997) Methane fluxes following slurry applications to grassland soils: laboratory experiments. *Agriculture, Ecosystems and Environment*, **63**, 51-60.

Chadwick, D.R. (2005) Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. *Atmospheric Environment*, **39**, 787–799.

Chambers, B.J., Lord, E.I., Nicholson, F.A. and Smith, K.A. (1999) Predicting nitrogen availability and losses following application of organic manure to arable land: MANNER. *Soil Use and Management*, **15**, 137-143.

Choudrie, S.L., Jackson, J., Watterson, J.D., Murrells, T., Passant, N., Thomson, A., Cardenas, L., Leech, A., Mobbs, D.C. and Thistlethwaite, G. (2008) UK Greenhouse Gas Inventory, 1990 to 2006: Annual Report for submission under the Framework Convention on Climate Change. AEAT/ENV/R/2582.

Clayton, H, McTaggart, I.P. and Parker, J. (1997) Nitrous oxide emissions from fertilised grassland: a 2 year study of the effects of N fertiliser form and environmental conditions. *Biology and Fertility of Soils*, **25**, 252 – 260.

Clemens, J., Trimborn, M., Weiland, P. and Amon, B. (2006) Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. *Agriculture, Ecosystems and Environment*, **112**, 171-177.

COGEA (for the EC), evaluation of Common Agricultural Policy measures in the rice sector, November 2009 http://ec.europa.eu/agriculture/eval/reports/rice/fulltext_en.pdf

Cole, C.V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., Paustian, K., Rosenberg, N., Sampson, N., Sauerbeck, D. and Zhao, Q. (1997) Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling in Agroecosystems*, **49**, 221–228.

Conant, R.T., Paustian, K. and Elliott, E.T. (2001) Grassland Management and Conversion into Grassland: Effects on Soil Carbon. *Ecological Applications*, **11**, 343-355.

Cowell, S.J. and Clift, R. (2000) A methodology for assessing soil quantity and quality in life cycle assessment. *Journal of Cleaner Production*, **8**(4), 321-331.

Commission of the European Communities (2006) Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC /* COM/2006/0232 final - COD 2006/0086 */.

Cruickshank, M.M., Tomlinson, R.W., Devine, P.M. and Milne, R. (1998) Carbon in the vegetation and soils of Northern Ireland. Biology and environment. Proceedings of the Royal Irish Academy 98B, 9-21.

Cuttle, S., Shepherd, M. and Goodlass, G. (2003) *A review of leguminous fertility-building crops, with particular reference to nitrogen fixation and utilisation*. Written as a part of Defra Project OF0316 'The development of improved guidance on the use of fertility-building crops in organic farming'

Dalgaard, T., Halberg, N. and Porter, R.P. (2001) A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture, Ecosystems and Environment*, **87**, 51-65.

Daskalopoulou, I. and Petrou, A. (2002) Utilising a farm typology to identify potential adopters of alternative farming activities in Greek agriculture, *Journal of Rural Studies*, **18(9)**, 95-103.

Davis, J., Mack, N. and Kirke, A. (1997) New perspectives on farm household incomes, *Journal of Rural Studies*, **13(1)**, 57-64.

Dawson, J.J.C. and Smith, P. (2007) Carbon losses from soil and its consequences for land-use management. *Science of the Total Environment*, **382**, 165–190.

Debaeke, P. and Aboundrare, A. (2004) Adaptation of crop management to water-limited environments. *European Journal of Agronomy*, **21**, 433-446.

de Bont, C.J.A.M and van Bommel, K.H.M. (2005) *Structurele veranderingen in de Nederlandse land- en tuinbouw*, Beweging door verschillen tussen bedrijven. LEI. The Hague.

Defra – UK Department for environment, food and rural affairs (2005) *EC Farm Structure Survey: Focus on holders in the UK*. Defra National Statistics, London.

Defra – UK Department for environment, food and rural affairs (2007) *Farm Classification in the United Kingdom*, https://statistics.defra.gov.uk/esg/asd/fbs/sub/stat_issue/improve.htm.

Defra (2009a) Observatory monitoring framework – indicator data sheet. Environmental impact: Biodiversity. Indicator DE5: Farmland bird populations. Crown copyright 2009.

Defra (2009b) Observatory monitoring framework – indicator data sheet. Environmental impact: Biodiversity. Indicator DE6: Farmland butterfly populations. Crown copyright 2009.

Defra (2009c) Observatory monitoring framework – indicator data sheet. Environmental impact: Biodiversity. Indicator DE7: Plant diversity in fields and field margins. Crown copyright 2009.

Derwent, R.G., Jenkin, M.E., Saunders, S.M. and Pilling, M.J. (1998) Photochemical ozone creation potentials for organic compounds in northwest Europe calculated with a Master Chemical Mechanism. *Atmospheric Environment*, **32**, 2429–2441.

Derwent, R.G., Jenkin, M.E., Passant, N.R. and Piling, M.J. (2007) Photochemical ozone creation potentials for organic compounds in north-west Europe calculated with a master chemical mechanism. *Atmospheric Environment*, **41**(12), 2570-2579.

De Vries, W., Kros, J., Oenema, O. and de Klein, J. (2003) Uncertainties in the fate of nitrogen II: A quantitative assessment of the uncertainties in major nitrogen fluxes in the Netherlands. *Nutrient Cycling in Agroecosystems*, **66**, 71-102.

Dewhurst, R.J., Mitton, A.M., Offer, N. W., and Thomas, C. (1996) Effects of the composition of grass silages on milk production and nitrogen utilization by dairy cows. *Animal Science*, **62**, 25–34.

Didden, W.A.M. (2001) Earthworm communities in grasslands and horticultural soils. *Biology and Fertility of Soils*, **33**, 111-117.

Divila, E. and Doilicha, T. (2005) Typology and income situation of farm households in the Czech Republic, *Politicka Ekonmie*, **53(4)**, 495-511.

Djurfeldt, G. and Waldenstrom, C. (1996) Towards a Theoretically Grounded Typology of Farms: A Swedish Case, *Acta Sociologica*, **39(2)**, 187-210.

Dobbie K.E. and Smith K.A. (2001) The effects of temperature, water-filled pore space and land use on N_2O emissions from an imperfectly drained gleysol. *European Journal of Soil Science*, **52**, 667–673.

Dobbie, K.E. and Smith, K.A. (2003) Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling variables. *Global Change Biology*, **9**, 204-218.

Dobbie, K.E., McTaggart, I.P. and Smith, K.E. (1999) Nitrous oxide emissions from intensive agricultural systems: variations between crops and seasons, key driving variables and mean emission factors. *Journal of Geophysical Research*, 104, 26891 – 26899.

Donaldson, J.V.G., Hutcheon, J. A., Jordan, V.W.L. and Osborne, N.J. (1994) Evaluation of energy usage for machinery operations in the development of more environmentally benign farming systems. *Aspects of Applied Biology*, **40**, Arable farming under CAP reform, 87-91.

Dubus, I., Azimonti, G., Bach, M., Barriuso, E., Bidoglio, G., Bouraoui, F., Centofanti, T., Coquet, Y., Feisel, B., Fialkiewicz, W., Fowler, H., Galimberti, F., Grizzetti, B., Højberg, A., Hollis, J., Jarvis, N., Kajewski, I., Kjær, J., Krasnicki, S., Lewis, K., Lobnik, F., Lolos, P., Moeys, J., Nolan, T., Rasmussen, P., Réal, B., Reichenberger, S., Šinkovec, M., Stenemo, F., Suhadolic, M., Surdyk, N., Tzilivakis, T., Vaudour, E., Avoulidou-Theodorou, E., Windhorst, D. and Wurm. P. (2009) The FOOTPRINT Software Tools: Pesticide Risk Assessment and Management in the EU at different spatial scales. Presented at CEMEPE & SECOTOX June 2009, Mykonos, Greece.

Duncan, K. (2008) Agricultural practices that reduce greenhouse gases (GHGs) and generate co-benefits. *Environmental Toxicology*, II: 61-69.

Dyson, K.E., Thomson, A.M., Mobbs, D.C., Milne, R., Skiba, U., Clark, A., Levy, P.E., Jones, S.K., Billett, M.F., Dinsmore, K.J., van Oijen, M., Ostle, N., Foereid, B., Smith, P., Matthews, R.W., Mackie, E., Bellamy, P., Rivas-Casado, M., Jordan, C., Higgins, A., Tomlinson, R. W., Grace, J., Parrish, P., Williams, M., Clement, R., Moncrieff, J. and Manning, A. (2009) *Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry*. Ed: K.E. Dyson. Annual Report, July 2009. Department for the Environment, Food and Rural Affairs Climate, Energy and Ozone: Science and Analysis Division Contract GA01088.

Edmund, M., Tavernier, A. and Tolomeo, V. B. (2004) Farm Typology and Sustainable Agriculture: Does Size Matter? *Journal of Sustainable Agriculture*, **24(2)**, 33-46.

Eggels, P.G., Ansems, A.M.M. and van Der Ven, B.L. (2001) *Eco-efficiency of recovery scenarios of plastic packaging*. TNO-report ref R 2000/119 for the Association of Plastics Manufacturers in Europe (APME), Brussels, Belgium.

Environment Agency (2004) Model Procedures for the Management of Land Contamination. Contaminated Land Report 11. Environment Agency.

European Commission (EC) (2005) *Soil ATLAS of Europe*. European Soil Bureau Network, 111.

European Commission (EC) (2006) Commission staff working document accompanying the communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions Thematic Strategy for Soil Protection impact assessment of the Thematic Strategy on Soil Protection {COM(2006)231 final}{SEC(2006)1165}. Brussels, 22.9.2006 SEC(2006)620.

European Commission: DEG Agriculture (2009). *Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions*. European Commission Joint Research Council project due for completion 2010.

European Commission (2010) Report from the Commission to the Council and the European Parliament on implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2004-2007 SEC(2010)118.

European Environment Agency (2008) *Annual European Community LRTAP Convention emission inventory report 1990–2006*. Submission to EMEP through the Executive Secretary of the UNECE. Luxembourg: Office for Official Publications of the European Communities, 2008.

Eurostat (2006) *Structure of agricultural holdings*, Reference Metadata in Euro SDMX Metadata Structure (ESMS), Compiled by the Statistical Office of the European Communities (Eurostat).

Eurostat (2009) *Agricultural statistics. Main results - 2007–08. 2009 edition*. Compiled by the Statistical Office of the European Communities (Eurostat). ISBN 978-92-79-12436-5

Eurostat (2010) *Fallow land and set-aside land: Number of farms and areas by size of farm (UAA) and size of arable area.* http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lu_ofsetasid&lang=en. Date accessed 11th August 2010

FAO – Food and Agriculture Organisation (2004) Twenty-Fourth FAO Regional Conference for Europe. International Year of Rice: 2004. Agenda Item 10. Montpellier, France, 5-7 May 2004

Falloon, P., Powlson D. and Smith, P. (2004) Managing field margins for biodiversity and carbon sequestration: a Great Britain case study. *Soil Use and Management*, **20**, 240-247.

Farmer, M., Cooper, T., Baldock, D., Tucker, G., Eaton, R., Hart, K. and Bartley, J. and Rayment, M. (2008) Reflecting environmental land use needs into EU policy: preserving and enhancing the environmental benefits of unfarmed features on EU farmland. Institute for European Environmental Policy Reference: ENV.B.1/ETU/2007/0033. Final Report.

Follett, R.F., Kimble, J.M. and Lal, R. (2001) *The potential of U.S. grazing lands to sequester soil carbon*. pp 401-430 in R. F. Follett, J. M. Kimble and R. Lal (eds). The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Boca Raton, FL.

Freeman, C., Ostle, N., and Kang, H. (2001) An enzymic 'latch' on a global carbon store. N*ature*, **409**, 149

Freibauer, A. (2003) Regionalised inventory of biogenic greenhouse gas emissions from European agriculture. *European Journal of Agronomy*, **19**, 135-160

Friedrich, R and Obermeier, A. (1999) Anthropogenic emissions of Volatile Organic Compounds. In: Hewitt., N. (Ed.) Reactive Hydrocarbons in the Atmosphere.

Garcia, P.G., Diaz, F.J.M., Sanchez , M.E., and Garcia, F.P. (2009) Assessment of the sustainability in Dehesa farms according to size and livestock prevalence, *Itea-Informacion Tecnica Economica Agraria*, **105(2)**, 117-141.

Ganuza, A. and Almendros, G. (2003) Organic carbon storage in soils of the Basque Country (Spain): The effect of climate, vegetation type and edaphic variables. Biological Fertility of Soils, 37, 154–162.

Godinho, M.F. and Coelho, M.L.M. (2005) From households to firms with independent legal status: the spectrum of institutional units in the development of European agriculture, Paper prepared for presentation at the 94th EAAE Seminar.

Gómez-Barbero, M. and Rodríguez-Cerezo, E. (2008) GM crops in EU agriculture. Case study for the BIO4EU project. Final Report for European Commission DG JRC - Institute for Prospective Technological Studies Sustainability in Agriculture, Food and Health Unit

Gomi, B., Hauck, H., Stoppera, S. and Preining, O. (2004) Spatial and temporal variations of PM1, PM2.5, PM10 and particle number concentration during the AUPHEP—project. *Atmospheric Environment*, **38**, 3917-3934.

Goulding, K.W.T., Webster, C.P., Powlson, D.S. and Poulton, P.R. (2006) Denitrification losses of nitrogen fertilizer applied to winter wheat following ley and arable rotations as estimated by acetylene inhibition and 15N balance. *European Journal of Soil Science*, **44**, 63-72.

GREENERGY (2008) Energy optimisation in European greenhouses. Deliverable 10: Software usability tests report. Wageningen University, January 2008.

Green, M., (1987) Energy in pesticide manufacture, distribution and use. In: Helsel, Z.R. (Ed) *Energy in Plant Nutrition and Pest Control*, **7**, Elsevier, Amsterdam, ISBN 0-444-42753-8, 165-177.

Groenestein, C. M., Van Faassen, H. G., 1996. Volatilization of ammonia, nitrous oxide and nitric oxide in deep-litter systems for fattening pigs. *Journal of Agricultural Engineering Research*, **65**, 269-274

Groot Koerkamp, P. W. G. and Uenk, G. H. (1997). *Climatic conditions and aerial pollutants in and emissions from commercial production systems in the Netherlands*. In: Voermans, J. A. M., Monteny, G. J. (Eds.), Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities. Research Station for Pig Husbandry (PV), Rosmalen, 139-144

Guinée, J.B. (2001) Life Cycle Assessment: An operational guide to the ISO standards. Centre of Environmental Science (CML), Leiden University, Netherlands.

Guinée, J.B. (ed) (2002) Handbook on life cycle assessment. Operational guide to the ISO standard. Dordrecht, Netherlands: Kluwer Academic Publishing.

Haas, G., Wetterich, F and Geier, U. (2000) Life Cycle Assessment Framework in Agriculture on the Farm Level. *The International Journal of Life Cycle Assessment*, **5**(6), 345-348

Härkönen, J., Valkonen, E., Kukkonen, J., Rantakrans, E., Jalkanen, L. and Lahtinen, K. (1995). An operational dispersion model for predicting pollution from a road. *Int. J. of Environment and Pollution*, **5**(4–6), 602–610.

Heisler, C. and Kaiser, E. A. (1995) Influence of Agricultural Traffic and Crop Management on Collembola and Microbial Biomass in Arable Soil. *Biology and Fertility of Soils*, **19**, 159-165

Heisler, C., Rogasik, H., Brunotte, J. and Joschko, M. (1998) Conservation tillage and biological activity. *Landbauforschung Volkenrode*, **48**, 199-212

Helgason, B.L., Janzen, H.H., Chantigny, M.H., Drury, C.F., Ellert, B.H., Gregorich, E.G., Lemke, R.L. and Pattey, E. (2005) Toward improved coefficients for predicting direct N_2O emissions from soils in Canadian Agroecosystems. *Nutrient Cycling in Agroecosystems*, **72**, 87-99.

Henke, R. (2007) Farm typologies and support policies in Italian agriculture, *Rivista dell'Associazione Rossi-Doria*, **2.**

Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R. F.A., Niemelä, J., Rebane, M., Wascher, D., Watt, A. and Young, J. (2008) Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe – A review. *Agriculture, Ecosystems and Environment*, **124**(1-2), 60-71

Hillier, J., Hawes, C., Squire, G., Hilton, A. Wale, S. and Smith, P. (2009) The carbon footprints of food crop production. *International Journal of Agricultural Sustainability*, **7**, 107-118.

Hodda, M. and Wanless, F.R. (1994) Nematodes from an English Chalk Grassland – Species Distributions. *Nematologica*, **40**, 116-132

Hodgkinson, R.A, Chambers, B. J., Withers, P.J.A and Cross, R. (2002). Phosphorus losses to surface waters following organic manure applications to a drained clay soil. *Agricultural Water Management,* **57**, 155-173.

Hoppe, R.A., Perry, J.E. and Banker, D. (2000) ERS Farm Typology for a Diverse Agricultural Sector. Economic Research Service of United States Department of Agriculture, *Information Bulletin No.* **759.**

Hörnig, G., Türk, M. and Wanka, U. (1999). Slurry Covers to reduce Ammonia Emission and Odour Nuisance. *Journal of Agricultural Engineering Research*, **73**, 151-157.

Hülsbergen, K.J. and Kalk, W.D. (2001) Energy balances in different agricultural systems - can they be improved? *The International Fertiliser Society Proceedings*, **476.**

Huijbregts, M.A.J. (2001) Uncertainty and variability in environmental life-cycle assessment. PhD thesis, University of Amsterdam, Amsterdam.

Hunt, D. (1995) *Farm Power and Machinery Management*. Ninth Edition. Iowa State University Press, Ames, Iowa.

Hurley, R. (1965) Problems Relating to Criteria for Classification of Farms, *Journal of Farm Economics*, 47:5, 1565-1571

IEC (2008) *Introduction, intended uses and key programme elements for Environmental Product Declarations, EPD*. International EPD Consortium (IEC). February 2008.

Iglesias, A., Avis, K., Benzie, M., Fisher, P., Harley, M., Hodgson, N., Horrocks, L., Moneo, M. and Webb, J. (2006) Adaptation to Climate Change in the Agricultural Sector AGRI-2006-G4-05. AEA Energy and Environment and Universidad de Politécnica de Madrid. Report to European Commission Directorate - General for Agriculture and Rural Development.

IPCC (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 3 Reference Manual*. J. T. Houghton et al., IPCC/OECD/IEA, Paris, France

IPCC (2000) *IPCC Special Report on Land Use, Land-Use Change and Forestry*, Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N. H., Verardo, D. J. and Dokken, D. J. (Eds.) Cambridge University Press, UK. pp 375.

IPCC (2003) *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Prepared by the National Greenhouse Gas Inventories Programme. Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K and Wagner, F. (eds) Published by the Institute for Global Environmental Strategies (IGES) for the IPCC.

IPCC (2006) *2006 Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa.

Jackson, J., Choudrie, S., Thistlethwaite, G., Passant, N., Murrells, T., Watterson, J., Mobbs, D., Cardenas, L., Thomson, A. and Leech, A. (2009) *UK Greenhouse Gas Inventory, 1990 to 2007: Annual Report for submission under the Framework Convention on Climate Change*. ISBN 0-9554823-8-0. http://www.airquality.co.uk/reports/cat07/0905131425_ukghgi-90
07_main_chapters_Issue2_UNFCCC_CA_v5_Final.pdf.

Janzen, H.H. (1987) Soil organic matter characteristics after long-term cropping to various spring wheat rotations. *Canadian Journal Soil Science*, **67**, 845–856.

Jenssen, T.K. and Kongshaug, G. (2003) Energy consumption and greenhouse gas emissions in fertiliser production. The International Fertiliser Society Proceedings, 509.

Johnston, A.E. (2008) Resource or waste: the reality of nutrient cycling to land. The International Fertiliser Society Proceedings, 630.

Johnson, K.A. and Johnson, D.E. (1995) Methane emissions from cattle. *Journal of Animal Science*, **73**, 2483–2492.

Jolliet, O., Brent, A., Goedkoop, M., Itsubo, N., Mueller-Wenk, R., Peña, C., Schenk, R., Stewart, M., Weidema. B., Bare, J., Heijungs, R., Pennington, D., Rebitzer, G., Suppen, N and Udo de Haes, H. (2003a) Life Cycle Impact Assessment Programme of the Life Cycle Initiative. Final report of the LCIA Definition study. Life Cycle Initiative.

Jolliet, O., Margni, O., Charles, R., Humbert, S., Payet, J., Rebitzer, G. and Rosenbaum, R. (2003b) IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. *Int. J. of Life Cycle Assessment*, **8**(6), 324–330

Jolliet, O., Müller-Wenk, R., Bare, J., Brent, A., Goedkoop, M., Heijungs, R., Itsubo, N., Peña, C., Pennington, D., Potting, J., Rebitzer, G., Stewart, M., Udo de Haes, H. and Weidema, B. (2004) *The LCIA Midpoint-damage Framework of the UNEP/SETAC Life Cycle Initiative*. The International Journal of Life Cycle Assessment, 9:6, 394-404.

Kalk, W.D. and Hülsbergen, K.J. (1999) Dieselkraftstoffeinsatz in der Pflanzenproduktion. *Landtechnik*, **54**, 332-333.

Karppinen, A., Kukkonen, J., Elol.ahde, T., Konttinen, M., Koskentalo, T., Rantakrans, E. (2000) A modelling system for predicting urban air pollution, model description and applications in the Helsinki metropolitan area. Atmospheric Environment, **34**, 3723–3733.

Kebraub, E., France, J., Beever, D.E. and Castillo, A.R. (2001) Nitrogen pollution by dairy cows and its mitigation by dietary manipulation. *Nutrient Cycling in Agroecosystems*, **60**, 275-285.

Kirkby, M. J., Jones, R. J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., van Lynden, G.J. and Huting, J.(2004) Pan-*European Soil Erosion*

Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). European Soil Bureau Research Report No.16, EUR 21176, 18pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg

King, J.A., Bradley, R.I., Harrison, R. and Carter, A.D. (2004) Carbon sequestration and saving potential associated with changes to the management of agricultural soils in England. *Soil Use and Management*, **20**, 394-402.

Körner, O., Warner, D.J., Tzilivakis, J., Eveleens, B. and Heuvelink, E. (2007) Decision support for optimising energy consumption in European greenhouses. GREENSYS 2007 organised by the International Society for Horticultural Science, Naples, Italy, 4-5th October 2007.

Kristensen, P. and Hansen, H.O. (1994) European rivers and lakes. Assessment of their environmental state. Environmental monographs, vol. 1. Copenhagen, Denmark: European Environmental Agency.

Kromm, D.E. and White, S.E. (1990) Variability in adjustment preferences to groundwater depletion in the American high plains. *Water Research Bulletin*, **22**, 791–801.

Kuipers H. and van De Zande, J.C. (1994) Quantification of traffic systems in crop production. In: Soane, B. D. and Ouwerkerk, C. (eds) Soil compaction in crop production. Amsterdam: Elsevier, 1994:417–45.

Külling, D.R., Menzi, H., Sutter, F., Lischer, P. Kreuzer, M. (2003) Ammonia, nitrous oxide and methane emissions from differently stored dairy manure derived from grass- and haybased rations. *Nutrient Cycling Agroecosystem*, **65**, 13–22.

Labouze, E., Honoré, C., Moulay, L., Couffignal, B. and Beekmann, M. (2004) Photochemical ozone creation potentials. A new set of characterization factors for different gas species on the scale of Western Europe. *The International Journal of Life Cycle Assessment*, **9**(3), 187-195.

Laczka, E. and Szabó, P. (2000) Definition of farms in the agricultural statistics of Hungary and the EU. Presented at the Conference of European Statisticians, 2000.

Lainsbury, M.A. (2009) *UK Pesticides Guide 2009*. British Crop Protection Council. CABI Publishing, CAB International, Wallingford, Oxford.

Lal, R. and Kimble, J.M. (1997) Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems*, **49**, 243-253.

Landais, E. (1998) Modelling Farm Diversity - New Approaches to Typology Building in France, *Agricultural Systems*, **58(4)**, 505-527

Leip, A. and Bocchi, S. (2007) *Contribution of rice production to greenhouse gas emissions in Europe*. In Bocchi, S., Ferrero, A. and Porro, A. (Eds). Proceedings of the Fourth Temperate Rice Conference, 25–28 June 2007, Novara, Italy 30-31

Lewis, K.A., Tzilivakis, J., Skinner, J.A., Finch, J., Kaho, T., Newbold, M.J. and Bardon, K.S. (1997). Scoring and ranking farmland conservation activities to evaluate environmental performance and encourage sustainable farming. *Sustainable Development,* **5(2)**, 71-78.

Lewis, K.A., Newbold, M.J. and Tzilivakis, J. (1999) Developing an emissions inventory from farm data. *Journal of Environmental Management* **55**, 183-197

Lewis, K.A., Tzilivakis, J., and Green, A. (2002) *Application of the sustainable agriculture indicators at farm level for England and Wales*. Final report for Department for Environment, Food and Rural Affairs (Defra) Project NT1855. October 2002.

Lewis, K.A., Brown, C.D., Hart, A. Tzilivakis, J. (2003) P-EMA: overview and application of a software system designed to assess the environmental risks of agricultural pesticides. *Agronomie*, **23**, 85-96.

Lewis, K.A., Green, A. and Tzilivakis, J. (2007) Development of an Improved Pesticide properties Database for Risk Assessment. Proceedings of the European Federation for IT in Agriculture (EFITA) conference 2-5 July 2007, Glasgow.

Li, C., Frolking, S. and Frolking, T.A. (2002) A model of nitrous oxide evolution from soil driven by rainfall events. 1. Model structure and sensitivity. *Journal of Geophysical Research*, **97**, 9759–9776.

Lillywhite, R.D., Chandler, D., Grant, W., Lewis, K., Firth, C., Schmutz, U. and Halpin, D. (2007) *Environmental footprint and sustainability of horticulture (including potatoes) - A comparison with other agricultural sectors*. 1 - 159, Defra, UK.

Loveland, P. J. and Webb, J. (2000) Critical levels of soil organic matter. Defra project report SP 0306. Available: http://www.defra.gov.uk/science/project_data/DocumentLibrary/SP0306/SP0306_216_FRP.pdf

Loveland, P.J., Thompson, T.R.E., Webb, J., Chambers, B., Jordan, C., Stevens, J., Kennedy, F., Moffat, A., Goulding, K.W.T., McGrath, S.P., Paterson, E., Black, H. and Hornung, M. (2002) Identification and development of a set of national indicators for soil quality. R&D Technical report P5-053/2/TR, Environment Agency, Swindon.

Lovett, D.K. and O'Mara, F.P. (2002) Estimation of enteric methane emissions originating from the national livestock beef herd: a review of the IPCC default emission factors. *Tearmann,* **2**, 77–83.

Lovett, D. K., Shalloo, L., Dillon, P. and O'Mara, F. P. (2006) A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime. *Agricultural Systems*, **88**, 156–179

Louwagie, G., Gay, S. H. and Burrell, A. (2009) *Sustainable Agriculture and Soil Conservation (SoCo)*. Final report. EUR 23820 EN – 2009. DG Agriculture and Rural Development, European Commission.

MacDonald, A.M., Matthews, K.B., Paterson, E. and Aspinall, R. J. (1994) The impact of climate-change on the soil-moisture regime of Scottish mineral soils. *Environmental Pollution*, **83**, 245–250.

Machefert, S.E., Dise, N.B., Goulding, K.W.T. and Whitehead, P.G. (2002) Nitrous oxide emission from a range of land uses across Europe. *Hydrology and Earth System Sciences*, **6**, 325-337.

Machmüller, A., Ossowski, D.A. and Kreuzer, M. (2000) Comparative evaluation of the effects of coconut oil, oilseeds and crystalline fat on methane release, digestion and energy balance in lambs. *Animal Feed Science and Technology*, **85**, 41–60.

Machmüller, A., Soliva, C.R. and Kreuzer, M. (2003) Methane suppressing effect of myristic acid in sheep as affected by dietary calcium and forage proportion. *British Journal of Nutrition*, **90**, 529–540.

Mack, N., Loughry, Y. and McDonald, C. (2006) A Socio-Economic Profile Of The Proposed Mournes National Park, RDC Policy and Innovation Research Unit, Rural Development Council, August 2006.

MAFF (2000) *Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209)*. Ministry of Agriculture, Fisheries and Food, The Stationary Office, Norwich, UK.

Marland, G., McCarl, B. A. and Schneider, U.A. (2001) Soil carbon: policy and economics. *Climate Change*, **51**, 101–117.

McCrabb, G.C. (2001) Nutritional options for abatement of methane emissions from beef and dairy systems in Australia. In Greenhouse gases and animal agriculture (eds J. Takahashi and B. A. Young), pp. 115–124. Amsterdam, The Netherlands: Elsevier.

McGinn, S.M., Beauchemin, K.A., Coates, T. and Colombatto, D. (2004) Methane emissions from beef cattle: effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. *Journal of Animal Science*, **82**, 3346–3356.

Merrington, G., Fishwick, S., Barraclough, D., Morris, J., Preedy, N., Boucard, T., Reeve, M., Smith, P. and Fang, C. (2006) The development and use of soil quality indicators for assessing the role of soil in environmental interactions. Environment Agency Science Report SC030265. ISBN: 1844325466, Environment Agency March 2006.

Milà i Canals, L., Cowell, S, J., Sim, S. and Basson, L., (2007) Comparing domestic versus imported apples: a focus on energy use. *Environmental Science Pollution Research*, **14**, 338-344.

Mills, J.A.N., Kebreab, E., Yates, C.M., Crompton, L.A., Cammell, S.B., Dhanoa, M.S., Agnew, R.E. and France, J. (2003) Alternative approaches to predicting methane emissions from dairy cows. *Journal of Animal Science*, **81**, 3141–3150.

Milne R. and Brown T.A. (1997) Carbon in the vegetation and soils on Great Britain. *Journal of Environmental Management*, **49**, 413–433.

Milne, R. and Mobbs, D. C. (eds) (2006) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. DEFRA Contract EPG 1/1/160

Monteny, G., Bannink, A. and Chadwick, D. (2006) Greenhouse gas abatement strategies for animal husbandry. *Agriculture, Ecosystems and Environment*, **112**, 163-170.

Moorby, J.M., Chadwick, D.R., Scholefield, D., Chambers, B.J. and Williams, J.R. (2007) *A review of best practice for reducing greenhouse gases*. Defra project report AC0206.

Morgan, J. and Pain, B.F. (2008) Anaerobic Digestion of Farm Manures and Other Products for Energy Recovery and Nutrient Recycling. International Fertiliser Society Proceedings 632.

Mosier, A.R., Halvorson, A.D., Peterson, G.A., Robertson, G.P., Sherrod, L. (2005) Measurement of net global warming potential in three agroecosystems. *Nutrient Cycling in Agroecosystems*, **72**, 67–76.

Mosier, A.R., Duxbury, J.M., Freney, J.R., Heinemeyer, O., Minami, K. and Johnson, D.E. (1998) Mitigating agricultural emissions of methane. *Climate Change*, **40**, 39–80.

Mudgal, S. and Turbé, A. (2010) *Soil biodiversity: functions, threats and tools for policy makers*. [Contract 07.0307/2008/517444/ETU/B1]. European Commission DG ENV. Final report February 2010.

Mueller-Wenk, R. (2002) Attribution to road traffic of the impact of noise on health. Environmental Series No. 339, BUWAL Bern.

National Non Foods Crop Centre (NNFC) (2010) *Renewable Materials Factsheet – Bioplastics*. The National Non-Food Crops Centre, Biocentre, York Science Park, Innovation Way, Heslington, York YO10 5DG, UK.

Natural England (2008) ELS Handbook 2nd edition October 2008.

Natural England (2010) Lost life: England's lost and threatened species. Natural England, ISBN 978-1-84754-192-5, Catalogue Code: NE233

Newbold, C. J. and Rode, L.M. (2005) *Dietary additives to control methanogenesis in the rumen*. In Second Int. Conf. on Greenhouse Gases and Animal Agriculture, Working Papers (eds C. R. Soliva, J. Takahashi, and M. Kreuzer), pp. 60–70. Zurich, Switzerland: ETH.

Newbold, C.J., Ouda, J.O., Lo´pez, S., Nelson, N., Omed, H., Wallace, R.J. and Moss, A.R. (2002) *Propionate precursors as possible alternative electron acceptors to methane in ruminal fermentation*. In Greenhouse gases and animal agriculture (eds J. Takahashi and B.A. Young), pp. 151–154. Amsterdam, The Netherlands: Elsevier.

Newbold, C.J., Lo´pez, S., Nelson, N., Ouda, J. O., Wallace, R. J. and Moss, A. R. (2005) Propionate precursors and other metabolic intermediates as possible alternative electron acceptors to methanogenesis in ruminal fermentation in vitro. *British Journal of Nutrition*, **94**, 27–35.

Oenema, O., Wrage, N., Velthof, G.L., van Groenigen, J.W., Dolfing, J. and Kuikman, P.J. (2005) Trends in global nitrous oxide emissions from animal production systems. *Nutrient Cycling in Agroecosystems*, **72**, 51–65.

Ogle, S.M., Breidt, F.J., Eve, M.D. and Paustian, K. (2003) Uncertainty in estimating land-use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. *Global Change Biology*, **9**, 1521-1542.

Oleson, J.E. and Bindi, M. (2002) Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy*, **16**, 239–262.

Olesen, J. E., Jensen, T. and Petersen, J. (2000) Sensitivity of field-scale winter wheat production in Denmark to climate variability and climate change. *Climate Research*, **15**, 221–238

Ostle, N.J., Levy, P.E., Evans, C.D. and Smith, P. (2009) UK land use and soil carbon sequestration. *Land Use Policy*, **26**, S274-S283.

Paustian, K., Babcock, B., Hatfield, J., Lal, R., McCarl, B., McLaughlin, S., Post, W., Mosier, A., Rice, C., Robertson, G., Rosenberg, J., Rosenzweig, C., Schlesinger, W. and Zilberman, D. (2004) *Agricultural mitigation of greenhouse gases: science and policy options*. Council on Agricultural Science and Technology (CAST) report, R141 2004, ISBN 1-887383-26-3, 120, May, 2004.

Pavao-Zuckerman, M.A. and Coleman, D.C. (2007) Urbanization alters the functional composition, but not taxonomic diversity, of the soil nematode community. *Applied Soil Ecology*, **35**, 329-339.

Pennington, D.W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T. and Rebitzer, G. (2004) Life cycle assessment Part 2: Current impact assessment practice. *Environment International*, **30**, 721– 739.

Pimentel, D. (1980) *Handbook of energy utilization in agriculture*. CRC Press, Inc. Boca Raton, Fla

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (1995) Environmental and Economic Costs of Soil Erosion and Conservation Benefits. Science (Washington D C) 267(5201), 1117-1123.

Powlson, D.S. Pruden, G., Johnston, A.E. and Jenkinson, D.S. (1986) The nitrogen cycle in the Broadbalk Wheat Experiment: recovery and losses of 15N-labelled fertilizer applied in spring and inputs of nitrogen from the atmosphere. *Journal of Agricultural Science*, **107**, 591-609.

Pretzer, D.D. and Finley, R.M. (1974) Farm Type Classification Systems: Another Look at an Old Problem, *American Journal of Agricultural Economics*, **56(1)**, 145-149.

Rahn, C.R., Greenwood, D.J. and Draycott, A. (1996) *Prediction of nitrogen fertilizer requirement with the HRI WELL-N computer model*. In: Progress in Nitrogen Cycling (Proceedings of the 8th Nitrogen Workshop held at the University of Ghent, 5-8 September, 1994.) ed. by: van Cleemput, O.; Hofman, G.; Vermoesen, A. 1996, p255-258; 21 ref.. Kluwer Academic Publishers; Dordrecht; Netherlands.

Regina, K., Lehtonen, H., Nousiainen, J. and Esala, M. (2009) Modelled impacts of mitigation measures on greenhouse gas emissions from Finnish agriculture up to 2020. *Agricultural and Food Science*, **18**, 477-493.

Renard, K.G., Foster, G.R., Weesies, G.A., Yoder, D.C. (1997) Predicting soil erosion by water. A guide to conservation planning with the universal soil loss equation (RUSLE). *Agricultural Handbook* **70.**

Riveiro, J.A., Marey, M.F., Marco, J.L. and Alvarez, C.J. (2008) Procedure for the classification and characterization of farms for agricultural production planning: Application in the Northwest of Spain, *Computers and Electronics in Agriculture*, **61(2)**, 169-178.

Rochette, P. and Janzen, H.H. (2005) Towards a revised coefficient for estimating N_2O emissions from legumes. *Nutrient Cycling in Agroecosystems*, **73**, 171–179.

Rosenbaum, R.K., Bachmann, T.M., Swirsky Gold, L., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M. McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D. and Hauschild, M.Z. (2008) USEtox - the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *Int. J. of Life Cycle Assessment*, **13(7)**, 532-546.

Rounsevell, M.D.A., Brignall, A.P. and Siddons, P.A., (1996) Potential climate change effects on the distribution of agricultural grassland in England and Wales. *Soil Use Management*, **12**, 44–51.

Sakellariou-Makrantonakia, M, Papalexisa, D. Nakosa, N. and Kalavrouziotis, I. K. (2007) Effect of modern irrigation methods on growth and energy production of sweet sorghum (var. Keller) on a dry year in Central Greece. *Agricultural Water Management*, **90**, 181-189.

Sartori, G. (1991) Comparing and miscomparing. *Journal of Theoretical Politics*, **3**, 243–257

Schelde, K., Olesen, J.E. and Weisbjerg, M.R. (2004) *MIDAIR. Definition of Conventional and Organic Dairy Farms in Five European Regions*. DJF Internal Report No. 206. Danish Institute of Agricultural Sciences, Tjele, Denmark, 69.

Schenk, U., Manderscheid, R., Hugen, J. and Weigel, H. J. (1995) Effects of CO_2 enrichment and intraspecific competition on biomass partitioning, nitrogen content and microbial biomass carbon in soil of perennial ryegrass and white clover. *Journal of Experimental Botany*, **46**, 987–993.

Schils, R.L.M., Oleson, J.E., del Prado, A. and Soussana, J.F. (2007) A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. *Livestock Science*, **112**, 240-251.

Serraj, R., Sinclair, T.R. and Allen, L.H. (1998) Soybean nodulation and N2 fixation response to drought under carbon dioxide enrichment. *Plant Cell Environment*, **21**, 491–500.

Shorten, P.R. and Pleasants, A.B. (2007) A stochastic model of urinary nitrogen and water flow in grassland soil in New Zealand. *Agriculture, Ecosystems and Environment,* **120**, 145–152.

Silgram, M. and Harrison, R. (1998) *Mineralisation of cover crop residues over the short and medium term*. Proceedings of the 3rd Workshop of EU Concerted Action 2108 Long-term reduction of nitrate leaching by cover crops, 30 September-3 October 1997, Southwell, UK. AB-DLO, Netherlands.

Silvis H.J. and van Bruchem, C. (ed.) (2005) *Agricultural economic report 2004 of the Netherlands*, LEI, The Hague.

Sinclair, T.R. and Seligman, N.G. (1995) Global environment change and simulated forage quality of wheat. I. Non stressed conditions. *Field Crops Research*, **40**, 19–27.

Skinner, J.A., Lewis, K.A., Bardon, K.S., Tucker, P., Catt, J.A. and Chambers, B.J. (1997) An Overview of the Environmental Impact of Agriculture in the U.K. *Journal of Environmental Management*, **50**: 111–128.

Smit, B. and Skinner, M.W. (2002) Adaptation options in agriculture to climate change: a typology. *Mitigation and Adaptation Strategies for Global Change*, **7(1)**, 85-114.

Smith, P., Martino, D., Cai, Z., Gwary D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S. (2007). Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems and Environment*, **118**. 6-28.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008a) Greenhouse gas mitigation in agriculture. *Philosophical Transactions Royal Society of London Biological Sciences*, **363**, 789-813.

Smith, W. N., Grant, B. B, Desjardins, R. L., Qian, B., Hutchinson, J. and Gameda, S. (2008b) Potential impact of climate change on carbon in agricultural soils in Canada 2000-2099. *Climatic Change*, **93**, 313-333

Smith, P., Powlson, D. S., Smith, J.U., Falloon, P. and Coleman, K. (2000a) Meeting the UK's climate change commitments: options for carbon mitigation on agricultural land. *Soil Use and Management*, **16**, 1-11

Smith, P., Powlson, D. S., Smith, J.U., Falloon, P. and Coleman, K. (2000b) Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. *Global Change Biology*, **6**, 525-539.

Smith, P., Milne, R., Powlson, D. S., Smith, J. U., Falloon, P. and Coleman, K. (2000c) Revised estimates of the carbon mitigation potential of UK agricultural land. *Soil Use and Management*, **16**, 293-295

Smith, J.U., Bradbury, N.J. and Addiscott, T.M. (1996) SUNDIAL: A PC-based system for simulating nitrogen dynamics in arable land. *Agronomy Journal*, **88**, 38-43.

Smith, K. A. and Conen, F. (2004) Impacts of land management on fluxes of trace greenhouse gases. *Soil Use Management*, **20**, 255–263.

Soane, B.D. and van Ouwerkerk, C. (Eds.) (1994) Soil compaction in crop production. *Developments in Agricultural Engineering*, **11**, Elsevier, Amsterdam.

Sommer, S.G. and Olesen, J.E., (2000) Modelling ammonia volatilization from animal slurry applied to cereals. *Atmospheric Environment*, **34**, 2361–2372

Sommer, S.G., Petersen, S.O., Sørensen, P., Poulsen, H.D. and Møller, H.D. (2007) Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. *Nutrient Cycling in Agroecosystems*, **78**, 27-36.

Sohngen, B., R. Mendelsohn (2003). "An optimal control model of forest carbon sequestration", American Journal of Agricultural Economics 85 (2) 448–457.

Soussana, J.F., Loiseau, P., Viuchard, N., Ceschia, E., Balesdent, J., Chevallier, T., Arrouays, D. (2004) Carbon cycling and sequestration opportunities in temperate grasslands. *Soil Use Management*, **20**, 219–230.

St Clair, S., Hiller, J. and Smith, P. (2008) Estimating the pre-harvest greenhouse costs of energy crop production. *Biomass and Bioenergy*, **32**, 442-452.

Stoate, C., Báldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L. and Ramwell, C. (2009) Ecological impacts of early 21st century agricultural change in Europe – A review. *Journal of Environmental Management*, **91**(1), 22-46.

Stohl, A. Hittenberger, M. and Wotaw, G. (1998) Validation of the lagrangian particle dispersion model FLEXPART against large-scale tracer experiment data. *Atmospheric Environment*, **32**, 4245-4264.

Thomas, C. (2004) *Feed into Milk (FiM): a New Applied Feeding System for Dairy Cows*. Nottingham University Press, UK.

Tubiello, F.N., Donatelli, M., Rosenzweig, C. and Stockle, C.O. (2000) Effects of climate change and elevated CO_2 on cropping systems: model predictions at two Italian locations. *European Journal of Agronomy*, **13**, 179–189.

Tzilivakis, J., Jaggard, K., Lewis, K.A., May, M. & Warner, D.J. (2005a) An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK. *Agricultural Systems*, **85**, 101-119.

Tzilivakis, J., Jaggard, K., Lewis, K.A., May, M. & Warner, D.J. (2005b) Environmental impact and economic assessment for UK sugar beet production systems. *Agriculture, Ecosystems and Environment*, **107**, 341-358.

Tzilivakis, J. and Lewis, K. A. (2007) *The Agricultural Document Library (ADLib) and its applications*. Proceedings of the European Federation for IT in Agriculture (EFITA) conference 2-5 July 2007, Glasgow.

Tzilivakis, J., Lewis, K.A., Warner, D.J. and Green, A. (2009) Assessment of Reduction in Environmental Burdens through Targeted Measures compared with Whole Farm Approaches in Cropping and Livestock Systems. Final report for Department for Environment, Food and Rural Affairs (Defra) Project IF0131, August 2009.

Tzilivakis, J., Lewis, K.A., Green, A. and Warner, D.J. (submitted) A Novel Technique for Identifying Environmental Outcomes from Agricultural Practices, *Impact Assessment and Project Appraisal journal*.

Udo de Haes, H.A., Jolliet, O., Finnveden, G., Hauschild, M., Krewitt, W. and Miiller-Wenk, R. (1999) Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment. Background Document for the Second Working Group on Life Cycle Impact Assessment of SETAC-Europe (WIA-2). *The International Journal of Life Cycle Assessment*, **4**(3), 167-174.

UK Quality Air Archive (2010) See http://www.airquality.co.uk/what_causes.php?n_action=pollutants&item=3, National Atmospheric Emissions Inventory http://www.naei.org.uk/. Accessed May 2010.

UNEP (2003) *Evaluation of Environmental Impacts in Life Cycle Assessment*. United Nations Environment Programme. ISBN: 92-807-2144-5.

UNEP (2009) *Towards Sustainable Production and Use of Resources: Assessing Biofuels.* United Nations Environment Programme's (UNEP) International Panel for Sustainable Resource Management.

University of Leiden (2009) Characterisation factors database November 2009. http://www.leidenuniv.nl/cml/ssp/projects/lca2/charac.html. Date accessed 12th January 2010.

USDA - United States Department of Agriculture (2000) Economic Research Service, A Farm Typology for a Diverse Agricultural Sector, Agriculture. *Information Bulletin Number* **759.**

USDA - United States Department of Agriculture and the World Bank (2001) *Farming Systems and Poverty: Improving farmers' livelihoods in a changing world*. Rome and Washington D.C. ISBN 92-5-104627-1.

van Aardenne, J. and Gros, V. (2005) Max Planck Institute for Chemistry, Mainz, Germany. http://www.geiacenter.org/reviews/naturalVOCa.html. Date accessed 31st March 2010.

van Amstel, M., de Brauw, C. Driessen, P. and Glasbergen, P. (2007a) The reliability of product-specific eco-labels as an agrobiodiversity management instrument. *Biodiversity and Conservation*, **16**, 4109–4129.

van Amstel, M., de Neve, W., de Kraker, J. and Glasbergen, P. (2007b) Assessment of the Potential of Ecolabels to Promote Agrobiodiversity. *Ambio*, **36**(7), 551-558.

van Camp, L., Bujarrabal, B., Gentile, A-R., Jones, R. J.A., Montanarella, L., Olazábal, C. and Selvaradjou, S-K. (2004) *Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection*. EUR 21319 EN/1- Working Group on Research.

van Minnen, J. G., Strengers, B. J., Eickhout, B., Swart, R. J. and Leemans, R. (2008) Quantifying the effectiveness of climate change mitigation through forest plantations and carbon sequestration with an integrated land-use model. *Carbon Balance and Management*, **3:3**, 20 pages.

van Nevel, C.J. and Demeyer, D.I. (1996) Influence of antibiotics and a deaminase inhibitor on volatile fatty acids and methane production from detergent washed hay and soluble starch by rumen microbes in vitro. *Animal Feed Science Technology*, **37**, 21–31.

Verheijen, F.G.A., Bellamy, P.H., Kibblewhite, M.G. and Gaunt, J.L. (2005) Organic carbon ranges in arable soils of England and Wales. *Soil Use and Management*, **21**, 2–9.

Waghorn, G.C., Tavendale, M.H., Woodfield, D.R. (2002). Methanogenesis from forages fed to sheep. Proceedings of New Zealand Society of Animal Production, **64**, 161–171.

Wallace, P., Brown, S. and McEwen, M. J. (2004) *To support the development of standards for compost by investigating the benefits and efficacy of compost in different applications*. Project Code: STA0015. The Waste and Resources Action Programme, Banbury, UK.

Warner, D.J. (2005) *Sustainability of the UK strawberry crop*. Final Report for project HH3606NSF undertaken by the University of Hertfordshire and East Malling Research for the Department for Environment, Food and Rural Affairs (Defra).

Warner, D. J. (2007) *Impact of Proposed NVZ Action Programme on Greenhouse Gas Emissions*. Final report for Department for Environment, Food and Rural Affairs (Defra) project WT0757NVZ.

Warner, D.J. (2008) *Research into the current and potential climate change mitigation impacts of environmental stewardship*. Final Report for Department for Environment, Food and Rural Affairs (Defra) Project BD2302.

Warner, D.J. Davies, M., Hipps, N., Osborne, N., Tzilivakis, J. and Lewis, K.A. (2010) Greenhouse gas emissions and energy use in UK grown short-day strawberry (*Fragaria xananassa*) crops. *Journal of Agricultural Science* in press.

Webb, J. and Misselbrook, T. H. (2004) A mass flow model of ammonia emissions from UK livestock production. *Atmosphere and Environment*, **38**, 2163-2176.

Weiske, A., Vabitscha, A., Olesen, J., Scheldek, K., Michel, J., Friedrich, R. and Kaltschmitt, M. (2006) Mitigation of greenhouse gas emissions in European conventional and organic dairy farming. *Agriculture, Ecosystems and Environment*, **112**, 221-232.

Wessex Water LTD. (2004). www.wessexwater.co.uk/strikingthebalance02/data_environment.

Wheeler, T.R., Ellis, R.H., Hadley, P., Morison, J.I.L., Batts, G.R. and Daymond, A.J. (1996) Assessing the effects of climate change on field crop production. *Aspects of Applied Biology*, **45**, 49–54.

Whitehouse, A. (2009) *Breeding strawberries for improved quality and reduced waste*. Presentation at Securing a safe and sustainable UK food supply. East Malling Research EMRA Day. 27 October 2009. East Malling Research, UK.

Wichtmann, W. and Joosten, H. (2007) Paludiculture: peat formation and renewable resources from rewetted peatlands. IMCG Newsletter 2007/3, 24-28.

Williams, A.G., Audsley, E. and Sandars, D.L. (2009) Environmental Burdens of Agricultural and Horticultural Commodity Production - LCA (IS0205) version 3. Cranfield University, UK.

Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities*. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

Wischmeier, W.H. and Smith, D.D. (1978) *Predicting rainfall erosion losses: a guide to conservation planning*. Agricultural Handbook No 537. US Dept of Agricultural Science and Education. Agricultural Research.

Wolf, J., (2000) *Modelling climate change impacts at the site scale on potato*. In: Downing, T.E., Harrison, P.A., Butterfield, R.E., Lonsdale, K.G. (Eds.), Climate Change, Climatic Variability and Agriculture in Europe. Environmental Change Unit, University of Oxford, UK, 135–154.

Wolin, E.A., Wolf, R.S. and Wolin, M.J. (1964) Microbial formation of methane. *Journal Bacteriology*, **87**, 993–998.

Worrall, F., Reed, M., Warburton, J., Burt, T. (2003) Carbon budget for a British upland peat catchment. *Science of the Total Environment*, **312(1-3)**, 133-146.

WRI and WBCSD (2004) The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard. Revised Edition. World Resources Institute and World Business Council for Sustainable Development, March 2004, ISBN 1-56973-568-9.

Wright, A.D.G., Kennedy, P., O'Neill, C.J., Troovey, A.F., Popovski, S., Rea, S.M., Pimm, C.L. and Klein, L. (2004) Reducing methane emissions in sheep by immunization against rumen methanogens. *Vaccine*, 22, 3976-3985.

Wurr, D.C.E., Hand, D.W., Edmondson, R.N., Fellows, J.R., Hannah, M.A. and Cribb, D.M. (1998) Climate change: a response surface study of the effects of CO_2 and temperature on the growth of beetroot, carrots and onions. *Journal of Agricultural Science*, 131, 125–133.

Xu, H., Cai, Z.C., Jia, Z.J. and Tsuruta, H. (2000) Effect of land management in winter crop season on CH_4 emission during the following flooded and rice-growing period. *Nutrient Cycling in Agroecosystems*, 58, 327–332.

Xu, H., Cai, Z.C. and Tsuruta, H. (2003) Soil moisture between rice-growing seasons affects methane emission, production, and oxidation. *Soil Science Society of America Journal*, 67, 1147–1157.

Yan, T., Agnew, R.E., Gordon, F.J. and Porter, M.G. (2000) Prediction of methane energy output in dairy and beef cattle offered grass silage-based diets. *Livestock Production Science*, 64, 253–263.

Yoemans, K.A. (1984) Is there an alternative to the European farm typology? *Journal of Applied Statistics*, 11:1, 88-119.

Zobel, T., Almroth, C., Bresky, J. and Burman, J-O. (2002) Identification and assessment of environmental aspects in an EMS context: an approach to a new reproducible method based on LCA methodology. *Journal of Cleaner Production*, **10**, 381–396.

Appendix A. Phase 2ii Case Studies

The following Phase 2ii case studies are presented in this appendix:

- **France**
  - Iffendic, France (dairy and cereals)
  - Leudeville, France (dairy, cereals and oilseeds)
  - La Touche Rolland, Talensac, France (dairy, cereals and protein crops)
- **Germany**
  - EAG Borna, Liebschützberg, Germany (cattle, dairy, pigs, cereals, oilseeds and root crops)
  - Gut Markee, Brandenburg, Germany (cereals and oilseeds
- **Hungary**
  - Hatvan, Hungary (cereals, field vegetables and protein crops)
  - Gödöllő, Szárítópuszta, Hungary (cereals and oilseeds)
  - Agrár-Béta, Birkamajor, Hungary (cereals, oilseeds and protein crops)
  - Lovasberény, Hungary (cattle, pigs, cereals, oilseeds and protein crops)
  - Karcsa, Hungary (cereals and oilseeds)
- **Italy**
  - Via Abbazia, Campagnola Emilia, Italy (pigs)
  - Ghiardo Di Bibbiano, Reggio Emilia, Italy (dairy)
- **Poland**
  - Wisznia Mala Farm, Wroclaw, Poland (cereals, oilseeds and root crops)
  - Ligota Piekna, Poland (cereals, oilseeds and root crops)
  - Rogozo, Poland (cereals, oilseeds and root crops)
  - Strseszow, Poland (dairy, cereals and oilseeds)
- **Slovenia**
  - Šetarova, Lenart V Sloven skih Goricah, Slovenia (cattle, cereals, oilseeds and protein crops)
  - Martjanci, Slovenia (cattle, pigs and cereals)
  - Bloke, Slovenia (cattle and cereals)
- **United Kingdom**
  - Drumdow, Stranraer, United Kingdom (cattle, sheep and cereals)
  - Viewfield, Castle Douglas, United Kingdom (cattle and sheep)

The data shown for each case study has been drawn from the IMPACCT software. The results tables have had some data removed due to space and layout requirements, but the key data has been kept. The following icon key applies to all the tables:

Icon key

	Potential negative environmental impact		Relative capital cost
	Potential positive environmental impact		Relative annual cost (benefit)
	Data quality: low , moderate , high		Relative annual cost (burden)

A1. France

A1.1. Iffendic, France (dairy and cereals)

Description

Enterprises:	• Cereals • Dairy (milk)
Components:	• Create grass strips on cultivated land • Create hedgerows on cultivated land • Create hedgerows on grassland • Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy manure storage • Dairy slurry storage • Harrow (triticale) • Harvest triticale • Load manure (grassland) • Milk cooling and storage • Milk plant cleaning • Milking machine (milking) • Mowing • Ploughing (triticale) • Solid manure (grassland) application • Solid manure (grassland) fate • Udder washing
Modifiers:	• Accurate milk tank thermostat: Yes • Archaeological features: No archaeological features • Biodiversity designations: None • Correct thermostat setting and regular checks for leaks: Yes • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: L. 6787 kgDM grazing • Dairy cow dietary additives used: Yes • Dairy cow improved breed: No • Dairy herd size: Medium (88-140 head) • Dairy manure store: Composting - passive windrow (irregular turning for mixing and aeration) • Dairy manure temperature: Unknown • Dairy slurry store: Uncovered anaerobic lagoon • Dairy slurry temperature: Unknown • Direct expansion refrigeration bulk tank: No • Distance between dairy manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Buildings): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • Heat recovery system to recycle heat removed from milk to heat wash water: No • High power to weight ratio tractor used: Yes • Improved milk tank and pipe insulation: Yes • Landscape designations: None • Location: Northern Europe • Manure application technique: Surface application • Manure application timing: Autumn • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Overpowered tractor not used: Yes • Ploughing depth: 15 cm • Pre-cool milk before storage tank: No • Rainfall: 600-700mm • Refrigeration condenser sufficiently ventilated: Yes • Soil type 1: Loam • Soil type 2: Organomineral • Soil type 4: Heavy / medium • Straw chopping: Yes • Types of harrow: Chain harrow • Types of manure applied: Cattle FYM - old • Types of mower: Mower-conditioner • Tyres inflated correctly: Yes • Vacuum pump with variable speed controls: No

	• Vehicles serviced regularly: Yes • Wash system: Hot wash

Item	Value
Number of dairy cattle	136
Percentage of year dairy cattle are housed	0 Percentage (0 to 100)
Area of cultivated land converted to grass strips	3 ha
Area of cultivated land converted to hedgerows	1.1 ha
Area of grassland converted to hedgerows	4.2 ha
Area of grassland cut	75 ha
Number of times per year that the grass is cut	1
Area of triticale harvested	15 ha
Tonnes of triticale harvested	67.5 t
Area harrowed (triticale)	15 ha
Area ploughed (triticale)	15 ha
Amount of cattle FYM (old) applied to grassland	400 t
Area of grassland to which solid manure is applied	45 ha
Thousands of litres of milk produced per year	460 Thousand litres (farm total)

Results summary:

Output	Quantity	Emissions	Sequestration
Triticale	67.5 Tonnes	0.021 tCO2e per tonne	0.313 tCO2 per tonne
Milk	460 Thousand litres (farm total)	3.168 tCO2e per thousand litres	0.035 tCO2 per thousand litres

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Environmental features	785.4	36.57 (for 0 to 140 years)	Potential physical improvement to soil Potential positive impact on invertebrate populations Potential positive impact on landscape quality Potential positive impact on bird populations		0%
Dairy cow	618.88				<1%-16%
Solid manure applications (grassland)	38.61	0.89 (for 713 years)			<1%
Dairy building	12.92				<1%
Grassland management	1.36				<1%
Harvesting (triticale)	0.7				0%
Seedbed preparation/soil management (triticale)	0.7				<1%
Total	**1458.57**	**37.46**			**<1%-16%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	13.7				
Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	10.2				
Dairy cow diet: D. 1949 kgDM grazing; 585 kgDM maize silage; 2339 wheat whole crop fermented; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	10				
Dairy cow diet: E. 1949 kgDM grazing; 2339 kgDM grass hay average; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	9.3				
Dairy cow diet: K. 1949 kgDM grazing; 1839 kgDM grass silage average; 585 kgDM maize silage; 2414 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	8				
Dairy cow diet: C. 1949 kgDM grazing; 585 kgDM maize silage; 2339 lucerne silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	6.4				
Dairy cow diet: I. 1559 kgDM grazing; 390 kgDM fodder beet; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	6.2				
Dairy cow diet: G. 1559 kgDM grazing; 390 kgDM	Dairy cow enteric fermentation-Dairy	5.6				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
kale; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage					
Dairy cow diet: A. 1949 kgDM grazing; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	5.6				
Dairy cow diet: H. 1559 kgDM grazing; 390 kgDM lucerne fresh; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	5.5				
Dairy cow diet: F. 1559 kgDM grazing; 390 kgDM clover; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	5.1				
Vacuum pump with variable speed controls: Yes	Milk plant cleaning-Milking machine (milking)	0.3				
Pre-cool milk before storage tank: Yes	Milk cooling and storage	0.1				
Heat recovery system to recycle heat removed from milk to heat wash water: Yes	Milk plant cleaning-Udder washing	0.1				
Wash system: Cold wash (using cleaning chemicals)	Milk plant cleaning	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area of grassland converted to hedgerows (ha)	4.2	187 tCO2e per ha	12.8	3.67	Potential positive impact on landscape quality Potential positive impact on bird populations	Reducing the area of grassland may have a direct economic impact on output, unless the land that is taken out of cultivation is of low productive capability.

Number of dairy cattle (head)	136	4.65 tCO2e per head	0.3	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Number of times per year that the grass is cut (Number)	1	1.36 tCO2e per Number	0.1	0		Unknown
Area harrowed (triticale) (ha)	15	0.02 tCO2e per ha	0	0		Unknown
Area ploughed (triticale) (ha)	15	0.03 tCO2e per ha	0	0		Unknown
Area of cultivated land converted to grass strips (ha)	3	0 tCO2e per ha	0	4.43	Potential physical improvement to soil Potential positive impact on invertebrate populations	Reducing the area of cultivated land may have a direct economic impact on crop output, unless the land that is taken out of cultivation is of low productive capability.
Area of cultivated land converted to hedgerows (ha)	1.1	0 tCO2e per ha	0	7.15	Potential positive impact on landscape quality Potential positive impact on bird populations	Reducing the area of cultivated land may have a direct economic impact on crop output, unless the land that is taken out of cultivation is of low productive capability.
Area of grassland cut (ha)	75	0.02 tCO2e per ha	0	0		Unknown
Tonnes of triticale harvested (tonne)	67.5	0.01 tCO2e per tonne	0	0		Reducing the amount of triticale harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of cattle FYM (old) applied to grassland (tonne)	400	0.1 tCO2e per tonne	0	0		Unknown
Area of triticale harvested (ha)	15	0.05 tCO2e per ha	0	0		Reducing the area of triticale may decrease total yield unless yields per hectare increase.
Area of grassland to which solid manure is applied (ha)	45	0.33 tCO2e per ha	0	0.02		Unknown

A1.2. Leudeville, France (dairy, cereals and oilseeds)

Description:

Enterprises:	• Cereals • Dairy (milk) • Oilseeds
Components:	• Create grass strips on cultivated land • Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy manure storage • Dairy slurry storage • Discing (oilseed rape) • Drilling (oilseed rape) • Harrow (barley) • Harrow (oilseed rape) • Harvest barley • Harvest oilseed rape • Harvest triticale • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (triticale) application • Inorganic fertiliser (triticale) fate • Inorganic fertiliser (triticale) manufacture • Milk cooling and storage • Milk plant cleaning • Milking machine (milking) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (triticale) • Pesticide application - solids (oilseed rape) • Pesticide application - solids (triticale) • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (triticale) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (oilseed rape) • Rolling (oilseed rape) • Subsoiling (35 cm) (oilseed rape)
Modifiers:	• Accurate milk tank thermostat: No • Archaeological features: No archaeological features • Biodiversity designations: None • Correct thermostat setting and regular checks for leaks: No • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Dairy cow dietary additives used: Yes • Dairy cow improved breed: Yes • Dairy herd size: Large (> 140 head) • Dairy manure store: Composting - static pile (forced aeration) • Dairy manure temperature: Unknown • Dairy slurry store: Liquid Aerobic treatment - forced aeration • Dairy slurry temperature: Unknown • Direct expansion refrigeration bulk tank: No • Distance between dairy manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: Yes • Driver aids used: No • Energy/fuel source (Buildings): Grid electricity • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Heat recovery system to recycle heat removed from milk to heat wash water: No

	• High power to weight ratio tractor used: No • Improved milk tank and pipe insulation: No • Location: Northern Europe • Maximum traction efficiency obtained (10-15% wheel slip): No • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Self-propelled sprayer • Ploughing depth: 20 cm • Pre-cool milk before storage tank: No • Rainfall forecasting used: No • Rainfall: <600mm • Refrigeration condenser sufficiently ventilated: No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 2: Organic • Soil type 3: Deep fertile silty soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Type of sub-soiling: Sub-soiling (7 legs) • Types of disc: Disc and pack • Types of drill: Combined harrow and drill • Types of harrow: Rotary cultivator (4 m) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vacuum pump with variable speed controls: No • Vehicles serviced regularly: Yes • Wash system: Cold wash (using cleaning chemicals)

Item	Value
Number of dairy cattle	138
Percentage of year dairy cattle are housed	100 Percentage (0 to 100)
Area of cultivated land converted to grass strips	11 ha
Area of barley harvested	73 ha
Tonnes of barley harvested	606 t
Area of oilseed rape harvested	50 ha
Tonnes of oilseed rape harvested	175 t
Area of triticale harvested	14 ha
Tonnes of triticale harvested	98 t
Area of wheat harvested	117 ha
Tonnes of wheat harvested	1053 t
Area of barley to which inorganic fertiliser is applied	73 Hectare
Amount of nitrogen applied to barley	8 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	50 ha
Amount of nitrogen applied to oilseed rape	9 Tonnes of Nitrogen
Area of triticale to which inorganic fertiliser is applied	14 ha
Amount of nitrogen applied to triticale	2 Tonnes of Nitrogen
Amount of insecticide used on barley	0 Kilograms of active substance
Amount of herbicide used on barley	131 Kilograms of active substance
Amount of fungicide used on barley	32 Kilograms of active substance
Area of oilseed rape sprayed with pesticides (liquids)	50 ha
Area of oilseed rape broadcast with pesticides (solids/granules)	0 ha
Amount of insecticide used on oilseed rape	7 Kilograms of active substance

Item	Value
Amount of herbicide used on oilseed rape	77 Kilograms of active substance
Amount of fungicide used on oilseed rape	9 Kilograms of active substance
Area of triticale sprayed with pesticides (liquids)	14 ha
Area of triticale broadcast with pesticides (solids/granules)	0 ha
Amount of insecticide used on triticale	0 Kilograms of active substance
Amount of herbicide used on triticale	1 Kilograms of active substance
Amount of fungicide used on triticale	3 Kilograms of active substance
Amount of fungicide used on wheat	91 Kilograms of active substance
Amount of herbicide used on wheat	103 Kilograms of active substance
Amount of insecticide used on wheat	0 Kilograms of active substance
Area harrowed (barley)	73 ha
Area ploughed (barley)	73 ha
Area discing (oilseed rape)	0 ha
Area drilled (oilseed rape)	0 ha
Area harrowed (oilseed rape)	50 ha
Area ploughed (oilseed rape)	50 ha
Area rolled (oilseed rape)	50 ha
Area subsoiled (oilseed rape)	0 ha
Thousands of litres of milk produced per year	1311 Thousand litres (farm total)

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	1053 Tonnes	0.008 tCO2e per tonne	0.012 tCO2 per tonne
Barley	606 Tonnes	0.106 tCO2e per tonne	0.02 tCO2 per tonne
Triticale	98 Tonnes	0.134 tCO2e per tonne	0.124 tCO2 per tonne
Oilseed rape	175 Tonnes	0.381 tCO2e per tonne	0.07 tCO2 per tonne
Milk	1311 Thousand litres (farm total)	0.345 tCO2e per thousand litres	0 tCO2 per thousand litres

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Dairy cow	441.16		Potential negative impact on air quality (-1380)		<1%-19%
Inorganic fertiliser (oilseed rape)	55.43		Potential negative impact on groundwater quality		<1%-6%
Inorganic fertiliser (barley)	49.41		Potential negative impact on groundwater quality		<1%-5%
Dairy building	12.88				<1%
Inorganic fertiliser (triticale)	12.33		Potential negative impact on groundwater quality		<1%

Seedbed preparation/soil management (barley)	9				<1%-1%
Seedbed preparation/soil management (oilseed rape)	6.84				<1%-1%
Harvesting (wheat)	6.15				<1%
Harvesting (barley)	3.77				<1%
Pesticides (wheat)	2.45				0%
Harvesting (oilseed rape)	2.29				<1%
Pesticides (barley)	2				0%
Pesticides (oilseed rape)	1.43				0%
Harvesting (triticale)	0.7				<1%
Pesticides (triticale)	0.13				0%
Environmental features	0	48.73 (for 24 years)	Potential physical improvement to soil Potential positive impact on invertebrate populations		0%
Total	**605.97**	**48.73**			**<1%-35%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (triticale) fate	11.9		Potential improvements to groundwater quality Potential improvements to groundwater quality		
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	6.5				
Dairy slurry store: Anaerobic digestion	Dairy slurry storage	10.1		Potential improvements to air quality	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Types of harrow: Spring tine harrows / weeding	Harrow (barley)-Harrow (oilseed rape)	0.8				
Types of harrow: Chain harrow	Harrow (barley)-Harrow (oilseed rape)	0.8				
Rainfall forecasting used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (triticale) fate	0.9				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (triticale) manufacture	0.7			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (oilseed rape)	0.5			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Pre-cool milk before storage tank: Yes	Milk cooling and storage	0.3				
Vacuum pump with variable speed controls: Yes	Milk plant cleaning-Milking machine (milking)	0.3				
Accurate milk tank thermostat: Yes	Milk cooling and storage	0.3				
Overpowered tractor not used: Yes	Harrow (barley)-Ploughing (barley)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Rolling (oilseed rape)	0.3				
Straw chopping: No	Harvest barley-Harvest oilseed rape-Harvest triticale-Harvest wheat	0.2				
Refrigeration condenser sufficiently ventilated: Yes	Milk cooling and storage	0.2				
Improved milk tank and pipe insulation: Yes	Milk cooling and storage	0.1				
Maximum traction efficiency obtained (10-15% wheel slip): Yes	Harrow (barley)-Ploughing (barley)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Rolling (oilseed rape)	0.1			- Ensuring maximum traction efficiency will reduce fuel use.	
Direct expansion refrigeration bulk tank: Yes	Milk cooling and storage	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to triticale (t)	2	6.16 tCO2e per t	1	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to oilseed rape (t)	9	6.16 tCO2e per t	1	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	8	6.18 tCO2e per t	1	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Number of dairy cattle (head)	138	3.29 tCO2e per head	0.5	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Percentage of year dairy cattle are housed (%)	100	1.28 tCO2e per %	0.2	0		Unknown
Tonnes of wheat harvested (tonne)	1053	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area harrowed (barley) (ha)	73	0.06 tCO2e per ha	0	0		Unknown
Area of wheat harvested (ha)	117	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of barley to which inorganic fertiliser is applied (ha)	73	0 tCO2e per ha	0	0		Unknown
Area of triticale harvested (ha)	14	0.05 tCO2e per ha	0	0		Reducing the area of triticale may decrease total yield unless yields per hectare increase.
Tonnes of triticale harvested (tonne)	98	0.01 tCO2e per tonne	0	0		Reducing the amount of triticale harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of oilseed rape harvested (tonne)	175	0.01 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	50	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape harvested (ha)	50	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Area of cultivated land	11	0 tCO2e per ha	0	4.43	Potential physical	Reducing the area of cultivated land may have a direct economic impact on crop output, unless

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
converted to grass strips (ha)					improvement to soil Potential positive impact on invertebrate populations	the land that is taken out of cultivation is of low productive capability.
Area of barley harvested (ha)	73	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	606	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area harrowed (oilseed rape) (ha)	50	0.06 tCO2e per ha	0	0		Unknown
Area ploughed (barley) (ha)	73	0.06 tCO2e per ha	0	0		Unknown
Amount of herbicide used on wheat (kg)	103	0.02 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on triticale (kg)	1	0.05 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Area of triticale sprayed with pesticides (liquids) (ha)	14	0.01 tCO2e per ha	0	0		Reducing the area triticale that is treated with pesticides could reduce triticale yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of fungicide used on triticale (kg)	3	0.02 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Area of triticale to which inorganic fertiliser is applied (ha)	14	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal and match crop requirements.
Amount of fungicide used on wheat (kg)	91	0.03 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on oilseed rape (kg)	9	0.13 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of	77	0.02 tCO2e	0	0		Reducing the amount of

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
herbicide used on oilseed rape (kg)		per kg				herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on oilseed rape (kg)	7	0.17 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape sprayed with pesticides (liquids) (ha)	50	0.01 tCO2e per ha	0	0		Unknown
Area ploughed (oilseed rape) (ha)	50	0.06 tCO2e per ha	0	0		Unknown
Amount of herbicide used on barley (kg)	131	0.02 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on barley (kg)	32	0.06 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area rolled (oilseed rape) (ha)	50	0.01 tCO2e per ha	0	0		Unknown

A1.3. La Touche Rolland, Talensac, France (dairy, cereals and protein crops)

Description:

Enterprises:	• Cereals • Dairy (milk) • Protein crops
Components:	• Create hedgerows on cultivated land • Create hedgerows on grassland • Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy manure storage • Dairy slurry storage • Harrow (maize) • Harrow (triticale) • Harvest triticale • Inorganic fertiliser (grassland) application • Inorganic fertiliser (grassland) manufacture • Inorganic fertiliser (triticale) application • Inorganic fertiliser (triticale) fate • Inorganic fertiliser (triticale) manufacture • Load manure (grassland) • Load manure (maize) • Milk cooling and storage • Milk plant cleaning • Milking machine (milking) • Mowing

	• Pesticide manufacture (maize) • Pesticide manufacture (triticale) • Slurry (maize) application • Slurry (maize) fate • Slurry (rye) application • Slurry (rye) fate • Solid manure (grassland) application • Solid manure (grassland) fate • Solid manure (maize) application • Solid manure (maize) fate • Udder washing
Modifiers:	• Accurate milk tank thermostat: Yes • Biodiversity designations: None • Correct thermostat setting and regular checks for leaks: Yes • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: L. 6787 kgDM grazing • Dairy cow dietary additives used: Yes • Dairy cow improved breed: No • Dairy herd size: Medium (88-140 head) • Dairy manure store: Composting - static pile (forced aeration) • Dairy manure temperature: Unknown • Dairy slurry store: Liquid/Slurry with natural crust cover • Dairy slurry temperature: Unknown • Direct expansion refrigeration bulk tank: No • Distance between dairy manure stores and surface water or drains: Greater than 10 metres • Driver aids used: Yes • Energy/fuel source (Buildings): Grid electricity • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Heat recovery system to recycle heat removed from milk to heat wash water: No • High power to weight ratio tractor used: No • Improved milk tank and pipe insulation: No • Landscape designations: None • Location: Northern Europe • Manure application technique: Soil incorporated (24 hours) • Manure application timing: Spring • Maximum traction efficiency obtained (10-15% wheel slip): No • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Pre-cool milk before storage tank: No • Rainfall forecasting used: No • Rainfall: <600mm • Refrigeration condenser sufficiently ventilated: Yes • Slurry application technique: Trailing hose • Slurry application timing: Spring • Slurry incorporation technique: Soil incorporated (< 6 hours) • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Clay • Soil type 2: Organomineral • Soil type 3: Medium and deep clay soils • Soil type 4: Heavy / medium • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of harrow: Spring tine harrows / weeding • Types of manure applied: Cattle FYM - old • Types of mower: Mower-conditioner • Types of pesticide: Fungicide, Herbicide, Insecticide • Types of slurry applied: Pig slurry (4% DM) • Tyres inflated correctly: Yes • Vacuum pump with variable speed controls: No • Vehicles serviced regularly: Yes • Wash system: Hot wash

Item	Value
Number of dairy cattle	50
Percentage of year dairy cattle are housed	25 Percentage (0 to 100)
Area of cultivated land converted to hedgerows	0.6 ha
Area of grassland converted to hedgerows	1 ha
Area of grassland cut	35 ha
Number of times per year that the grass is cut	2
Area of triticale harvested	14 ha
Tonnes of triticale harvested	840 t
Area of grassland to which inorganic fertiliser is applied	80 ha
Amount of nitrogen applied to grassland	12 Tonnes of Nitrogen
Area of triticale to which inorganic fertiliser is applied	28.6 ha
Amount of nitrogen applied to triticale	5.5 Tonnes of Nitrogen
Amount of insecticide used on maize	120.5 Kilograms of active substance
Amount of herbicide used on maize	18.7 Kilograms of active substance
Amount of fungicide used on maize	0 Kilograms of active substance
Amount of insecticide used on triticale	0 Kilograms of active substance
Amount of herbicide used on triticale	80 Kilograms of active substance
Amount of fungicide used on triticale	82.6 Kilograms of active substance
Area harrowed (maize)	14 ha
Area harrowed (triticale)	14 ha
Amount of pig slurry (4% DM) applied to maize	190 t
Amount of pig slurry (4% DM) applied to rye	0 t
Amount of cattle FYM (old) applied to grassland	0 t
Area of grassland to which solid manure is applied	0 ha
Amount of cattle FYM (old) applied to maize	180 t
Area of maize to which solid manure is applied	4.5 ha
Thousands of litres of milk produced per year	316 Thousand litres (farm total)
Tonnes of maize harvested	420 t
Tonnes of rye harvested	0 t

Results summary:

Output	Quantity	Emissions	Sequestration
Triticale	840 Tonnes	0.056 tCO2e per tonne	0.003 tCO2 per tonne
Maize	420 Tonnes	0.063 tCO2e per tonne	0.015 tCO2 per tonne
Milk	316 Thousand litres (farm total)	1.395 tCO2e per thousand litres	0.012 tCO2 per thousand litres

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Dairy cow	243.29				<1%-21%
Environmental features	187	7.96 (for 0 to 140 years)	Potential positive impact on landscape quality Potential positive impact on bird populations		0%
Inorganic fertiliser (triticale)	43.03		Potential negative impact on groundwater quality		<1%-6%
Solid manure applications (maize)	18.04	4 (for 158 years)			<1%
Slurry applications (maize)	6.03		Potential negative impact on air quality		<1%
Dairy building	4.9				<1%
Inorganic fertiliser (grassland)	4.19				<1%
Pesticides (maize)	2.21				0%
Pesticides (triticale)	2.06				0%
Harvesting (triticale)	1.62				<1%
Grassland management	1.39				<1%
Seedbed preparation/soil management (triticale)	0.24				0%
Seedbed preparation/soil management (maize)	0.24				0%
Slurry applications (rye)	0				0%
Solid manure applications (grassland)	0				0%
Total	**514.25**	**11.96**			**<1%-28%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	14.3				
Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	10.9				
Dairy cow diet: D. 1949 kgDM grazing; 585 kgDM maize silage; 2339 wheat whole crop fermented; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	10.7				
Dairy cow diet: E. 1949 kgDM grazing; 2339 kgDM grass hay average; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	10				
Dairy cow diet: K. 1949 kgDM grazing; 1839 kgDM grass silage average; 585 kgDM maize silage; 2414 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	9.1				
Dairy cow diet: C. 1949 kgDM grazing; 585 kgDM maize silage; 2339 lucerne silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	7.7				
Dairy cow diet: I. 1559 kgDM grazing; 390 kgDM fodder beet; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	7.1				
Dairy cow diet: A. 1949 kgDM grazing; 2339 kgDM	Dairy cow enteric fermentation-Dairy	6.6				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage					
Dairy cow diet: H. 1559 kgDM grazing; 390 kgDM lucerne fresh; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	6.5				
Dairy cow diet: G. 1559 kgDM grazing; 390 kgDM kale; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	6.5				
Dairy cow diet: F. 1559 kgDM grazing; 390 kgDM clover; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy cow excreta (deposition on pasture)-Dairy manure storage-Dairy slurry storage	6.1				
Nitrification inhibitors used: Yes	Inorganic fertiliser (triticale) fate	5.2		Potential improvements to groundwater quality		
Dairy slurry store: Anaerobic digestion	Dairy slurry storage	5.1		Potential improvements to air quality	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Dairy slurry store: Liquid Aerobic treatment - forced aeration	Dairy slurry storage	3.8		Potential decrease in air quality	- New slurry store may cost	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy slurry store: Liquid Aerobic treatment - natural aeration	Dairy slurry storage	3.1		Potential decrease in air quality	- New slurry store may cost typically between €10 and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy slurry temperature: <10 C	Dairy slurry storage	1.6		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Dairy slurry temperature: 12 C	Dairy slurry storage	0.9		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (grassland) manufacture-Inorganic fertiliser (triticale) manufacture	0.8			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Rainfall forecasting used: Yes	Inorganic fertiliser (triticale) fate	0.4				
Vacuum pump with variable speed controls: Yes	Milk plant cleaning-Milking machine (milking)	0.3				
Maximum traction efficiency obtained (10-15% wheel slip): Yes	Mowing-Slurry (maize) application-Solid manure (maize) application	0.2			- Ensuring maximum traction efficiency will reduce fuel use.	
Pre-cool milk before storage tank: Yes	Milk cooling and storage	0.1				
Types of mower: Mower	Mowing	0.1				
Heat recovery system to recycle heat removed from milk to heat wash water: Yes	Milk plant cleaning-Udder washing	0.1				
Wash system: Cold wash (using cleaning chemicals)	Milk plant cleaning	0.1				
High power to weight ratio tractor used: Yes	Mowing-Slurry (maize) application-Solid manure (maize) application	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area of grassland converted to hedgerows (ha)	1	187 tCO_2e per ha	36.4	3.67	Potential positive impact on landscape quality Potential positive impact on bird	Reducing the area of grassland may have a direct economic impact on output, unless the land that is taken out of cultivation is of low productive capability.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
					populations	
Amount of nitrogen applied to triticale (t)	5.5	7.82 tCO2e per t	1.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal.
Number of dairy cattle (head)	50	4.96 tCO2e per head	1	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Area of maize to which solid manure is applied (ha)	4.5	1.43 tCO2e per ha	0.3	0.89		Unknown
Number of times per year that the grass is cut (Number)	2	0.7 tCO2e per Number	0.1	0		Unknown
Amount of nitrogen applied to grassland (t)	12	0.35 tCO2e per t	0.1	0		Changes in N applied may have a significant impact on grass growth and yields. Review N use practices to ensure they are optimal.
Percentage of year dairy cattle are housed (%)	25	0.63 tCO2e per %	0.1	0		Unknown
Area of grassland to which inorganic fertiliser is applied (ha)	80	0 tCO2e per ha	0	0		Unknown
Area of cultivated land converted to hedgerows (ha)	0.6	0 tCO2e per ha	0	7.15	Potential positive impact on landscape quality Potential positive impact on bird populations	Reducing the area of cultivated land may have a direct economic impact on crop output, unless the land that is taken out of cultivation is of low productive capability.
Area of grassland cut (ha)	35	0.04 tCO2e per ha	0	0		Unknown
Area of triticale harvested (ha)	14	0.12 tCO2e per ha	0	0		Reducing the area of triticale may decrease total yield unless yields per hectare increase.
Tonnes of triticale harvested (tonne)	840	0 tCO2e per tonne	0	0		Reducing the amount of triticale harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of maize harvested (tonne)	420	0 tCO2e per tonne	0	0		Reducing the amount of maize harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of insecticide used on maize (kg)	120.5	0.02 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Area harrowed (triticale) (ha)	14	0.02 tCO2e per ha	0	0		Unknown
Amount of cattle FYM (old) applied to maize (tonne)	180	0.1 tCO2e per tonne	0	0.02		Unknown
Amount of pig slurry (4% DM) applied to maize (tonne)	190	0.03 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Area harrowed (maize) (ha)	14	0.02 tCO2e per ha	0	0		Unknown
Amount of herbicide used on maize (kg)	18.7	0.12 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on triticale (kg)	82.6	0.02 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on triticale (kg)	80	0.03 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Area of triticale to which inorganic fertiliser is applied (ha)	28.6	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal and match crop requirements.

A2. Germany

A2.1. EAG Borna, Liebschützberg, Germany (cattle, dairy, pigs, cereals, oilseeds and root crops)

Description:

Enterprises:	• Cattle rearing • Cereals • Dairy (milk) • Oilseeds • Pig fattening • Pig rearing • Root crops
Components:	• Bailing (barley) • Bailing (wheat) • Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy lighting • Dairy manure storage • Dairy slurry storage • Discing (oilseed rape) • Discing (rye) • Discing (sugar beet) • Discing (triticale) • Discing (wheat) • Drilling (oilseed rape) • Drilling (rye) • Drilling (sugar beet) • Drilling (triticale) • Drilling (wheat) • Harvest barley • Harvest oilseed rape • Harvest rye • Harvest wheat • Indoor breeding unit heating, lighting and ventilation • Indoor breeding unit manure storage • Indoor breeding unit slurry storage • Indoor finishers (heavy) heating, lighting and ventilation • Indoor finishers (heavy) manure storage • Indoor finishers (heavy) slurry storage • Indoor weaners heating, lighting and ventilation • Indoor weaners manure storage • Indoor weaners slurry storage • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (grassland) application • Inorganic fertiliser (grassland) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (rye) application • Inorganic fertiliser (rye) fate • Inorganic fertiliser (rye) manufacture • Inorganic fertiliser (sugar beet) application • Inorganic fertiliser (sugar beet) fate • Inorganic fertiliser (sugar beet) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Load manure (barley) • Load manure (grassland) • Load manure (oilseed rape) • Load manure (rye) • Load manure (sugar beet) • Load manure (wheat)

	• Milk cooling and storage • Milk plant cleaning • Milking machine (milking) • Mowing • Pesticide application - liquids (barley) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (rye) • Pesticide application - liquids (sugar beet) • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (rye) • Pesticide manufacture (sugar beet) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (oilseed rape) • Ploughing (rye) • Ploughing (sugar beet) • Ploughing (triticale) • Ploughing (wheat) • Rake • Rolling (oilseed rape) • Rolling (rye) • Rolling (sugar beet) • Rolling (triticale) • Rolling (wheat) • Slurry (barley) application • Slurry (barley) fate • Slurry (grassland) application • Slurry (grassland) fate • Slurry (oilseed rape) application • Slurry (oilseed rape) fate • Slurry (rye) application • Slurry (rye) fate • Slurry (sugar beet) application • Slurry (sugar beet) fate • Slurry (wheat) application • Slurry (wheat) fate • Solid manure (barley) application • Solid manure (barley) fate • Solid manure (grassland) application • Solid manure (grassland) fate • Solid manure (oilseed rape) application • Solid manure (oilseed rape) fate • Solid manure (rye) application • Solid manure (rye) fate • Solid manure (sugar beet) application • Solid manure (sugar beet) fate • Solid manure (wheat) application • Solid manure (wheat) fate • Subsoiling (35 cm) (barley) • Subsoiling (35 cm) (oilseed rape) • Subsoiling (35 cm) (rye) • Subsoiling (35 cm) (sugar beet) • Subsoiling (35 cm) (triticale) • Subsoiling (35 cm) (wheat) • Udder washing
Modifiers:	• Accurate milk tank thermostat: Yes • Archaeological features: No archaeological features • Automatic lighting controls: No • Correct siting and accurate temperature sensors: Yes • Correct thermostat setting and regular checks for leaks: Yes • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: A. 1949 kgDM grazing; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Dairy cow dietary additives used: Yes • Dairy cow improved breed: Yes • Dairy herd size: Large (> 140 head)

- Dairy manure store: Composting - intensive windrow (regular turning for mixing and aeration)
- Dairy manure temperature: Unknown
- Dairy slurry store: Liquid/Slurry with natural crust cover
- Dairy slurry temperature: Unknown
- Direct expansion refrigeration bulk tank: Yes
- Distance between dairy manure stores and surface water or drains: Greater than 10 metres
- Do not cultivate in poor conditions: Yes
- Driver aids used: Yes
- Enclosed creep, heater lamp automatic control and dimmer switches: Yes
- Energy/fuel source (Buildings): Gas/diesel oil
- Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil
- Energy/fuel source (Production of pesticides): Gas/diesel oil
- Energy/fuel source (Vehicles): Gas/diesel oil
- Ensure insulation always dry: Yes
- Fans interlinked to heaters (heaters on only when fans low): Yes
- Heat recovery system to recycle heat removed from milk to heat wash water: Yes
- High power to weight ratio tractor used: Yes
- Improved milk tank and pipe insulation: Yes
- Insulated enclosed creep: No
- Location: Northern Europe
- Low energy lighting: No
- Lying area panels on flat decks: Yes
- Manure application technique: Soil incorporated (24 hours)
- Manure application timing: Summer
- Maximum traction efficiency obtained (10-15% wheel slip): No
- Nitrate Vulnerable Zone (NVZ): No
- Nitrification inhibitors used: No
- Overpowered tractor not used: No
- Pesticide sprayer equipment: Tractor and sprayer
- Pig housing - Low energy lighting: No
- Pig housing ventilation - Fan and ventilation functioning optimally and openings checked frequently for obstructions: Yes
- Pig housing ventilation - Flat deck with correct number of fans : Yes
- Pig indoor breeding unit size: Large (over 2100 head)
- Pig Indoor finishers (heavy) unit size: Small (up to 1200 head)
- Pig indoor weaners unit size: Large (over 2100 head)
- Pig manure store: Solid storage (unconfined piles or stacks)
- Pig manure temperature: Unknown
- Pig slurry store: Liquid/Slurry with natural crust cover
- Pig slurry temperature: Unknown
- Ploughing depth: 20 cm
- Pre-cool milk before storage tank: No
- Rainfall forecasting used: Yes
- Rainfall: <600mm
- Refrigeration condenser sufficiently ventilated: Yes
- Slurry application technique: Trailing hose
- Slurry application timing: Autumn
- Slurry incorporation technique: Soil incorporated (6-8 hours)
- Soil Nitrogen Supply (SNS) known: Yes
- Soil type 1: Loam
- Soil type 2: Mineral
- Soil type 3: Light sand soils
- Soil type 4: Sand
- Straw chopping: No
- Type of inorganic fertiliser: Ammonium nitrate (34.5% N)
- Type of sub-soiling: Sub-soiling tramlines only (3 legs)
- Types of disc: Disc and pack
- Types of drill: Combined harrow and drill
- Types of manure applied: Poultry (layer) litter
- Types of mower: Mower-conditioner
- Types of pesticide: Fungicide, Herbicide, Insecticide
- Types of rake: Rake
- Types of slurry applied: Anaerobically digested dairy slurry (6% DM)
- Tyres inflated correctly: Yes
- Under floor heating, heated pads: Yes
- Vacuum pump with variable speed controls: Yes
- Vehicles serviced regularly: Yes
- Wash system: Cold wash (using cleaning chemicals)

Item	Value
Number of dairy cattle	340
Percentage of year dairy cattle are housed	100 Percentage (0 to 100)
Area of grassland cut	112 ha
Number of times per year that the grass is cut	4
Area of barley harvested	183 ha
Tonnes of barley harvested	68 t
Area of oilseed rape harvested	195 ha
Tonnes of oilseed rape harvested	42 t
Area of rye harvested	70 ha
Tonnes of rye harvested	75 t
Area of wheat harvested	234 ha
Tonnes of wheat harvested	72 t
Number of pigs (Indoor breeding unit)	540
Percentage of year pigs (indoor breeding) unit is occupied	100 Percentage (0 to 100)
Number of pigs (Indoor finishers - heavy)	250
Percentage of year pigs (indoor finishers - heavy) unit is occupied	100 Percentage (0 to 100)
Number of pigs (Indoor weaners)	1800
Percentage of year pigs (indoor weaners) unit is occupied	100 Percentage (0 to 100)
Area of barley to which inorganic fertiliser is applied	183 Hectare
Area of grassland to which inorganic fertiliser is applied	56 ha
Area of oilseed rape to which inorganic fertiliser is applied	195 ha
Area of rye to which inorganic fertiliser is applied	70 ha
Area of sugar beet to which inorganic fertiliser is applied	57 ha
Area of wheat to which inorganic fertiliser is applied	234 ha
Area of barley sprayed with pesticides (liquids)	183 ha
Area of oilseed rape sprayed with pesticides (liquids)	195 ha
Area of rye sprayed with pesticides (liquids)	70 ha
Area of sugar beet sprayed with pesticides (liquids)	57 ha
Area of wheat sprayed with pesticides (liquids)	234 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	72 Tonnes	0.203 tCO2e per tonne	0 tCO2 per tonne
Barley	68 Tonnes	0.249 tCO2e per tonne	0 tCO2 per tonne
Rye	75 Tonnes	0.01 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	42 Tonnes	0.307 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Dairy cow	3911.7				<1%-71%
Indoor breeding unit	296.49		Potential negative impact on air quality		<1%-6%
Indoor weaners	28.88		Potential negative impact on air quality		<1%-1%
Indoor finishers (heavy)	28.2		Potential negative impact on air quality		<1%-0%
Grassland management	17.11				<1%
Harvesting (wheat)	15.2				<1%
Dairy building	14.81				0%
Harvesting (barley)	11.9				<1%
Harvesting (oilseed rape)	7.54				0%
Harvesting (rye)	2.77				0%
Pesticides (wheat)	1.45				0%
Pesticides (oilseed rape)	1.21				0%
Pesticides (barley)	1.13				0%
Inorganic fertiliser (wheat)	1.03				0%
Inorganic fertiliser (oilseed rape)	0.86				0%
Inorganic fertiliser (barley)	0.81				0%
Pesticides (rye)	0.43				0%
Pesticides (sugar beet)	0.35				0%
Inorganic fertiliser (rye)	0.31				0%
Inorganic fertiliser (sugar beet)	0.25				0%
Inorganic fertiliser (grassland)	0.25				0%
Total	**4342.69**				**<1%-78%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Dairy manure store: Composting - in-vessel (forced aeration and continuous mixing)	Dairy manure storage	51.5				
Dairy manure store: Composting - static pile (forced aeration)	Dairy manure storage	51.5				
Dairy manure store: Solid storage (unconfined piles or stacks)	Dairy manure storage	49.6				
Dairy manure store: Composting - passive windrow (irregular turning for mixing and aeration)	Dairy manure storage	48.8				
Dairy manure store: Deep bedding - no mixing (stored for <1 month)	Dairy manure storage	47.9				
Dairy manure store: Deep bedding - no mixing (stored for >1 month)	Dairy manure storage	32.7				
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	31.1				
Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	17.4				
Dairy cow diet: D. 1949 kgDM grazing; 585 kgDM maize silage; 2339 wheat whole crop fermented; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	16.7				
Dairy manure store: Deep bedding - active mixing (stored for <1 month)	Dairy manure storage	15.4				
Dairy cow diet: E. 1949 kgDM grazing; 2339 kgDM grass hay average; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	14				
Dairy slurry store: Anaerobic digestion	Dairy slurry storage	15.6		Potential improvements		

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
				to air quality	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Dairy slurry store: Liquid Aerobic treatment - forced aeration	Dairy slurry storage	10.7		Potential decrease in air quality	- New slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy slurry store: Liquid Aerobic treatment - natural aeration	Dairy slurry storage	8		Potential decrease in air quality	- New slurry store may cost typically between €10 and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy cow diet: C. 1949 kgDM grazing; 585 kgDM maize silage; 2339 lucerne silage; 1914 kgDM	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	4.3				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)						
Dairy slurry temperature: <10 C	Dairy slurry storage	4.4		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Pig slurry store: Liquid Aerobic treatment - forced aeration	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	4.4		Potential decrease in air quality Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Pig slurry store: Pit storage below animal confinements (stored for <1 month)	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	4.3		Potential decrease in air quality Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Pig slurry store: Anaerobic digestion	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	5.7		Potential improvements to air quality Potential improvements to air quality Potential	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
				improvements to air quality	available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Dairy cow diet: K. 1949 kgDM grazing; 1839 kgDM grass silage average; 585 kgDM maize silage; 2414 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	2.8				
Pig slurry store: Liquid Aerobic treatment - natural aeration	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	3.7		Potential decrease in air quality Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy cow diet: I. 1559 kgDM grazing; 390 kgDM fodder beet; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	2.3				
Dairy slurry temperature: 12 C	Dairy slurry storage	2.5		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Dairy cow diet: L. 6787 kgDM grazing	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	1.5				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Pig slurry temperature: <10 C	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	1.8		Potential improvements to air quality Potential improvements to air quality Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Pig slurry temperature: 12 C	Indoor breeding unit slurry storage-Indoor finishers (heavy) slurry storage-Indoor weaners slurry storage	1		Potential improvements to air quality Potential decrease in air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Pig manure store: Composting - in-vessel (forced aeration and continuous mixing)	Indoor breeding unit manure storage-Indoor finishers (heavy) manure storage-Indoor weaners manure storage	0.8				
Pig manure store: Composting - static pile (forced aeration)	Indoor breeding unit manure storage-Indoor finishers (heavy) manure storage-Indoor weaners manure storage	0.8				
Dairy manure store: Deep bedding - active mixing (stored for >1 month)	Dairy manure storage	0.2				
Types of mower: Mower	Mowing	0.1				
Overpowered tractor not used: Yes	Mowing-Rake-Bailing (barley)-Bailing (wheat)	0.1				
Pig manure store: Composting - passive windrow (irregular turning for mixing and aeration)	Indoor breeding unit manure storage-Indoor finishers (heavy) manure storage-Indoor weaners manure storage	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Percentage of year dairy cattle are housed (%)	100	31.41 tCO2e per %	0.7	0		Unknown
Number of dairy cattle (head)	340	11.55 tCO2e per head	0.3	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Number of times per year that the grass is cut (Number)	4	4.28 tCO2e per Number	0.1	0		Unknown
Percentage of year pigs (indoor breeding) unit is occupied (%)	100	2.96 tCO2e per %	0.1	0	Potential negative impact on air quality	Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Tonnes of rye harvested (tonne)	75	0.04 tCO2e per tonne	0	0		Reducing the amount of rye harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of wheat harvested (tonne)	72	0.13 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of rye harvested (ha)	70	0.04 tCO2e per ha	0	0		Reducing the area of rye may decrease total yield unless yields per hectare increase.
Area of wheat harvested (ha)	234	0.06 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of oilseed rape harvested (ha)	195	0.04 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Tonnes of oilseed rape harvested (tonne)	42	0.18 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of grassland cut (ha)	112	0.15 tCO2e per ha	0	0		Unknown
Area of barley harvested (ha)	183	0.07 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	68	0.1 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Number of pigs (Indoor breeding unit) (head)	540	0.55 tCO2e per head	0	0	Potential negative impact on	Reducing the number of pigs will directly reduce output unless output per pig can be increased.

					air quality	
Area of wheat sprayed with pesticides (liquids) (ha)	234	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of sugar beet sprayed with pesticides (liquids) (ha)	57	0.01 tCO2e per ha	0	0		Reducing the area sugar beet that is treated with pesticides could reduce sugar beet yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of barley sprayed with pesticides (liquids) (ha)	183	0.01 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	234	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of oilseed rape sprayed with pesticides (liquids) (ha)	195	0.01 tCO2e per ha	0	0		Unknown
Percentage of year pigs (indoor finishers - heavy) unit is occupied (%)	100	0.28 tCO2e per %	0	0	Potential negative impact on air quality	Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Area of rye sprayed with pesticides (liquids) (ha)	70	0.01 tCO2e per ha	0	0		Reducing the area rye that is treated with pesticides could reduce rye yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of sugar beet to which inorganic fertiliser is applied (ha)	57	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on sugar beet yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of rye to which inorganic fertiliser is applied (ha)	70	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on rye yields. Review your N use practices to ensure they are optimal and match crop requirements.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	195	0 tCO2e per ha	0	0		Unknown
Area of grassland to which inorganic	56	0 tCO2e per ha	0	0		Unknown

fertiliser is applied (ha)						
Number of pigs (Indoor weaners) (head)	1800	0.02 tCO2e per head	0	0	Potential negative impact on air quality	Reducing the number of pigs will directly reduce output unless output per pig can be increased.
Percentage of year pigs (indoor weaners) unit is occupied (%)	100	0.29 tCO2e per %	0	0	Potential negative impact on air quality	Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Area of barley to which inorganic fertiliser is applied (ha)	183	0 tCO2e per ha	0	0		Unknown
Number of pigs (Indoor finishers - heavy) (head)	250	0.11 tCO2e per head	0	0	Potential negative impact on air quality	Reducing the number of pigs will directly reduce output unless output per pig can be increased.

A2.2. Gut Markee, Brandenburg, Germany (cereals and oilseeds)

Description:

Enterprises:	• Cereals • Oilseeds
Components:	• Create hedgerows on cultivated land • Harrow (oilseed rape) • Harrow (rye) • Harrow (triticale) • Harrow (wheat) • Harvest barley • Harvest oilseed rape • Harvest rye • Harvest triticale • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (rye) application • Inorganic fertiliser (rye) fate • Inorganic fertiliser (rye) manufacture • Inorganic fertiliser (triticale) application • Inorganic fertiliser (triticale) fate • Inorganic fertiliser (triticale) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Load manure (barley) • Load manure (oilseed rape) • Load manure (triticale) • Pesticide application - liquids (barley) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (rye) • Pesticide application - liquids (triticale) • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape)

	• Pesticide manufacture (rye) • Pesticide manufacture (triticale) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (oilseed rape) • Ploughing (triticale) • Ploughing (wheat) • Solid manure (barley) application • Solid manure (barley) fate • Solid manure (oilseed rape) application • Solid manure (oilseed rape) fate • Solid manure (triticale) application • Solid manure (triticale) fate
Modifiers:	• Archaeological features: No archaeological features • Biodiversity designations: None • Correct tyres used (reduce rolling resistance): Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: No • Landscape designations: None • Manure application technique: Soil incorporated (24 hours) • Manure application timing: Autumn • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 25 cm • Rainfall forecasting used: Yes • Rainfall: <600mm • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Sand • Soil type 2: Mineral • Soil type 3: Light sand soils • Soil type 4: Sand • Straw chopping: No • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of harrow: Power harrow • Types of manure applied: Poultry (broiler/turkey) litter • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of cultivated land converted to hedgerows	5 ha
Area of barley harvested	183 ha
Tonnes of barley harvested	1375 t
Area of oilseed rape harvested	295 ha
Tonnes of oilseed rape harvested	1180 t
Area of rye harvested	163 ha
Tonnes of rye harvested	1060 t
Area of triticale harvested	150 ha
Tonnes of triticale harvested	1000 t
Area of wheat harvested	227 ha
Tonnes of wheat harvested	1700 t
Area of barley to which inorganic fertiliser is applied	183 Hectare

Item	Value
Amount of nitrogen applied to barley	45 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	295 ha
Amount of nitrogen applied to oilseed rape	88 Tonnes of Nitrogen
Area of rye to which inorganic fertiliser is applied	163 ha
Amount of nitrogen applied to rye	45 Tonnes of Nitrogen
Area of triticale to which inorganic fertiliser is applied	150 ha
Amount of nitrogen applied to triticale	31 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	227 ha
Amount of nitrogen applied to wheat	80 Tonnes of Nitrogen
Area of barley sprayed with pesticides (liquids)	183 ha
Amount of insecticide used on barley	19 Kilograms of active substance
Amount of herbicide used on barley	137 Kilograms of active substance
Amount of fungicide used on barley	129 Kilograms of active substance
Area of oilseed rape sprayed with pesticides (liquids)	295 ha
Amount of insecticide used on oilseed rape	59 Kilograms of active substance
Amount of herbicide used on oilseed rape	177 Kilograms of active substance
Amount of fungicide used on oilseed rape	59 Kilograms of active substance
Area of rye sprayed with pesticides (liquids)	163 ha
Amount of insecticide used on rye	0 Kilograms of active substance
Amount of herbicide used on rye	120 Kilograms of active substance
Amount of fungicide used on rye	85 Kilograms of active substance
Area of triticale sprayed with pesticides (liquids)	150 ha
Amount of insecticide used on triticale	15 Kilograms of active substance
Amount of herbicide used on triticale	112 Kilograms of active substance
Amount of fungicide used on triticale	105 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	227 ha
Amount of fungicide used on wheat	38 Kilograms of active substance
Amount of herbicide used on wheat	170 Kilograms of active substance
Amount of insecticide used on wheat	23 Kilograms of active substance
Area ploughed (barley)	183 ha
Area harrowed (oilseed rape)	145 ha
Area ploughed (oilseed rape)	150 ha
Area harrowed (rye)	163 ha
Area harrowed (triticale)	100 ha
Area ploughed (triticale)	47 ha
Area harrowed (wheat)	200 ha
Area ploughed (wheat)	27 ha
Amount of poultry (broiler/turkey) litter applied to barley	450 t
Area of barley to which solid manure is applied	90 ha
Amount of poultry (broiler/turkey) litter applied to oilseed rape	1475 t
Area of oilseed rape to which solid manure is applied	295 ha
Amount of poultry (broiler/turkey) litter applied to triticale	375 t

Item	Value
Area of triticale to which solid manure is applied	75 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	1700 Tonnes	0.293 tCO2e per tonne	0.004 tCO2 per tonne
Barley	1375 Tonnes	0.299 tCO2e per tonne	0.006 tCO2 per tonne
Rye	1060 Tonnes	0.262 tCO2e per tonne	0.007 tCO2 per tonne
Triticale	1000 Tonnes	0.304 tCO2e per tonne	0.008 tCO2 per tonne
Oilseed rape	1180 Tonnes	0.808 tCO2e per tonne	0.006 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (oilseed rape)	519.89		Potential negative impact on groundwater quality		<1%-14%
Inorganic fertiliser (wheat)	472.48		Potential negative impact on groundwater quality		<1%-13%
Solid manure applications (oilseed rape)	403.32	0.5 (for 564 years)			<1%-2%
Inorganic fertiliser (barley)	265.97		Potential negative impact on groundwater quality		<1%-7%
Inorganic fertiliser (rye)	265.9		Potential negative impact on groundwater quality		<1%-7%
Inorganic fertiliser (triticale)	183.31		Potential negative impact on groundwater quality		<1%-5%
Solid manure applications (barley)	123.05	0.5 (for 564 years)			<1%-1%
Solid manure applications (triticale)	102.54	0.5 (for 564 years)			<1%-1%
Seedbed preparation/soil management (oilseed rape)	14.76				<1%
Harvesting (oilseed rape)	12.69				0%
Seedbed preparation/soil management (wheat)	11.4				<1%
Harvesting (wheat)	10.68				0%
Seedbed preparation/soil management (barley)	9.11				<1%
Harvesting (barley)	8.61				0%
Seedbed preparation/soil management (rye)	8.2				<1%
Harvesting (rye)	7.48				0%
Seedbed preparation/soil	7.37				<1%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
management (triticale)					
Harvesting (triticale)	6.91				0%
Pesticides (oilseed rape)	5.39				0%
Pesticides (barley)	4.61				0%
Pesticides (wheat)	4.08				0%
Pesticides (triticale)	3.75				0%
Pesticides (rye)	3.4				0%
Environmental features	0	35.75 (for 32 to 140 years)	Potential positive impact on landscape quality Potential positive impact on bird populations		0%
Total	**2454.89**	**37.25**			**<1%-51%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emission	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (rye) fate-Inorganic fertiliser (triticale) fate-Inorganic fertiliser (wheat) fate	42.8		Potential improvements to groundwater quality Potential improvements to groundwater quality Potential improvements to groundwater quality		
Manure application timing: Spring	Solid manure (barley) fate-Solid manure (oilseed rape) fate-Solid manure (triticale) fate	3.4	1.5			
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (rye) manufacture-	2.8			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and	

Modification	Components	% reduction of total emission	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	Inorganic fertiliser (triticale) manufacture-Inorganic fertiliser (wheat) manufacture				recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Types of harrow: Spring tine harrows / weeding	Harrow (oilseed rape)-Harrow (rye)-Harrow (triticale)-Harrow (wheat)	0.8				
Types of harrow: Chain harrow	Harrow (oilseed rape)-Harrow (rye)-Harrow (triticale)-Harrow (wheat)	0.8				
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (triticale)	0.4			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Ploughing depth: 20 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (triticale)	0.2			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25	

Modification	Components	% reduction of total emission	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Types of harrow: Rotary cultivator (4 m)	Harrow (oilseed rape)-Harrow (rye)-Harrow (triticale)-Harrow (wheat)	0.1				
High power to weight ratio tractor used: Yes	Ploughing (barley)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Harrow (rye)-Harrow (triticale)-Ploughing (triticale)-Harrow (wheat)-Solid manure (barley) application-Solid manure (oilseed rape) application-Solid manure (triticale) application	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to barley (t)	45	5.91 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to triticale (t)	31	5.91 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to rye (t)	45	5.91 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on rye yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	80	5.91 tCO2e per t	0.2	0	Potential negative impact on groundwater	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
					quality	optimal.
Amount of nitrogen applied to oilseed rape (t)	88	5.91 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Area of triticale to which inorganic fertiliser is applied (ha)	150	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of rye to which inorganic fertiliser is applied (ha)	163	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on rye yields. Review your N use practices to ensure they are optimal and match crop requirements.
Amount of fungicide used on barley (kg)	129	0.03 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on barley (kg)	19	0.19 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of barley sprayed with pesticides (liquids) (ha)	183	0.01 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	227	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	295	0 tCO2e per ha	0	0		Unknown
Amount of herbicide used on barley (kg)	137	0.03 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of triticale to which solid manure is applied (ha)	75	1.07 tCO2e per ha	0	0.01		Unknown
Amount of poultry (broiler/turkey) litter applied to triticale (tonne)	375	0.27 tCO2e per tonne	0	0		Unknown
Area of rye harvested (ha)	163	0.05 tCO2e per ha	0	0		Reducing the area of rye may decrease total yield unless

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
						yields per hectare increase.
Area of oilseed rape harvested (ha)	295	0.04 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	1375	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of barley harvested (ha)	183	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of oilseed rape harvested (tonne)	1180	0.01 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of rye harvested (tonne)	1060	0.01 tCO2e per tonne	0	0		Reducing the amount of rye harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of barley to which inorganic fertiliser is applied (ha)	183	0 tCO2e per ha	0	0		Unknown
Area of triticale harvested (ha)	150	0.05 tCO2e per ha	0	0		Reducing the area of triticale may decrease total yield unless yields per hectare increase.
Tonnes of wheat harvested (tonne)	1700	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	227	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Tonnes of triticale harvested (tonne)	1000	0.01 tCO2e per tonne	0	0		Reducing the amount of triticale harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape sprayed with pesticides (liquids) (ha)	295	0.01 tCO2e per ha	0	0		Unknown
Amount of insecticide used on oilseed rape (kg)	59	0.07 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	177	0.02 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
						pesticide use strategy to ensure it is optimal.
Area harrowed (wheat) (ha)	200	0.05 tCO2e per ha	0	0		Unknown
Area harrowed (triticale) (ha)	100	0.05 tCO2e per ha	0	0		Unknown
Area harrowed (rye) (ha)	163	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (oilseed rape) (ha)	150	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (triticale) (ha)	47	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (wheat) (ha)	27	0.05 tCO2e per ha	0	0		Unknown
Amount of fungicide used on oilseed rape (kg)	59	0.07 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of poultry (broiler/turkey) litter applied to barley (tonne)	450	0.27 tCO2e per tonne	0	0		Unknown
Area of oilseed rape to which solid manure is applied (ha)	295	1.07 tCO2e per ha	0	0		Unknown
Amount of poultry (broiler/turkey) litter applied to oilseed rape (tonne)	1475	0.27 tCO2e per tonne	0	0		Unknown
Area of barley to which solid manure is applied (ha)	90	1.07 tCO2e per ha	0	0.01		Unknown
Area harrowed (oilseed rape) (ha)	145	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (barley) (ha)	183	0.05 tCO2e per ha	0	0		Unknown
Amount of insecticide used on wheat (kg)	23	0.13 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on wheat (kg)	170	0.02 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on rye (kg)	85	0.03 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce rye yields. Review the pesticide use strategy to ensure it is optimal.
Amount of	120	0.02 tCO2e	0	0		Reducing the amount of

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
herbicide used on rye (kg)		per kg				herbicide used could reduce rye yields. Review the pesticide use strategy to ensure it is optimal.
Area of rye sprayed with pesticides (liquids) (ha)	163	0.01 tCO2e per ha	0	0		Reducing the area rye that is treated with pesticides could reduce rye yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of triticale sprayed with pesticides (liquids) (ha)	150	0.01 tCO2e per ha	0	0		Reducing the area triticale that is treated with pesticides could reduce triticale yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of insecticide used on triticale (kg)	15	0.2 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on triticale (kg)	112	0.03 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	38	0.08 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat sprayed with pesticides (liquids) (ha)	227	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of fungicide used on triticale (kg)	105	0.03 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Area of cultivated land converted to hedgerows (ha)	5	0 tCO2e per ha	0	7.15	Potential positive impact on landscape quality Potential positive impact on bird populations	Reducing the area of cultivated land may have a direct economic impact on crop output, unless the land that is taken out of cultivation is of low productive capability.

A3. Hungary

A3.1. Hatvan, Hungary (cereals, field vegetables and protein crops)

Description:

Enterprises:	• Cereals • Field vegetables • Protein crops
Components:	• Harvest wheat • Inorganic fertiliser (maize) application • Inorganic fertiliser (maize) fate • Inorganic fertiliser (maize) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide application - liquids (maize) • Pesticide application - liquids (wheat) • Pesticide manufacture (maize) • Pesticide manufacture (wheat) • Ploughing (maize) • Ploughing (wheat) • Prevention of compaction on cultivated land (maize) • Prevention of compaction on cultivated land (wheat)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Grid electricity • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: No • Maximum traction efficiency obtained (10-15% wheel slip): No • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 20 cm • Rainfall forecasting used: No • Rainfall: 600-700mm • Soil aerator used on compacted areas (cultivated land): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 3: Deep fertile silty soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of wheat harvested	1 ha
Tonnes of wheat harvested	6 t
Area of maize to which inorganic fertiliser is applied	0.5 ha
Amount of nitrogen applied to maize	0.035 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	1 ha
Amount of nitrogen applied to wheat	0.2 Tonnes of Nitrogen
Area of maize sprayed with pesticides (liquids)	0.5 ha
Amount of insecticide used on maize	0 Kilograms of active substance

Item	Value
Amount of herbicide used on maize	0.001 Kilograms of active substance
Amount of fungicide used on maize	0 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	0.5 ha
Amount of fungicide used on wheat	0.001 Kilograms of active substance
Amount of herbicide used on wheat	0.002 Kilograms of active substance
Amount of insecticide used on wheat	0.001 Kilograms of active substance
Area ploughed (maize)	0.5 ha
Total area of maize	0.5 ha
Area ploughed (wheat)	1 ha
Total area of wheat	1 ha
Tonnes of maize harvested	4.5 t

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	6 Tonnes	0.245 tCO2e per tonne	0 tCO2 per tonne
Maize	4.5 Tonnes	0.104 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	1.36		Potential negative impact on groundwater quality		<1%-47%
Seedbed preparation/soil management (wheat)	0.06				<1%-3%
Harvesting (wheat)	0.05				<1%
Seedbed preparation/soil management (maize)	0.03				<1%-2%
Pesticides (wheat)	0				0%
Pesticides (maize)	0				0%
Inorganic fertiliser (maize)	0.44		Potential negative impact on groundwater quality		<1%-15%
Total	**1.94**				**<1%-67%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (maize) fate- Inorganic fertiliser (wheat) fate	56.2		Potential improvements to groundwater quality		

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (maize) manufacture- Inorganic fertiliser (wheat) manufacture	5.2			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Rainfall forecasting used: Yes	Inorganic fertiliser (maize) fate- Inorganic fertiliser (wheat) fate	4.6				
Ploughing depth: 15 cm	Ploughing (maize)- Ploughing (wheat)	2.1			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Straw chopping: No	Harvest wheat	0.5				
Nitrification inhibitors used: No	Inorganic fertiliser (maize) fate- Inorganic fertiliser (wheat) fate	0.5				
Rainfall forecasting used: No	Inorganic fertiliser (maize) fate-	0.5				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	Inorganic fertiliser (wheat) fate					
Ploughing depth: 20 cm	Ploughing (maize)-Ploughing (wheat)	0.5			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Do not cultivate in poor conditions: Yes	Ploughing (maize)-Ploughing (wheat)	0.5			- Wet weather, can cause machinery damage and damage to soil structure.	
Soil Nitrogen Supply (SNS) known: Yes	Inorganic fertiliser (maize) fate-Inorganic fertiliser (wheat) fate	0.5			- Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Do not cultivate in poor conditions: No	Ploughing (maize)-Ploughing (wheat)	0.5			- Wet weather, can cause machinery damage and damage to soil structure.	

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to wheat (t)	0.2	6.8 tCO2e per t	10.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area ploughed (wheat) (ha)	1	0.06 tCO2e per ha	3.1	0		Unknown
Area ploughed (maize) (ha)	0.5	0.06 tCO2e per ha	3.1	0		Unknown
Area of wheat harvested (ha)	1	0.05 tCO2e per ha	2.6	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Amount of nitrogen applied to maize (t)	0.035	12.57 tCO2e per t	1.8	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal.
Tonnes of wheat harvested (tonne)	6	0.01 tCO2e per tonne	0.4	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of maize sprayed with pesticides (liquids) (ha)	0.5	0 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of maize to which inorganic fertiliser is applied (ha)	0.5	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of wheat to which inorganic fertiliser is applied (ha)	1	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Tonnes of maize harvested (tonne)	4.5	0 tCO2e per tonne	0	0		Reducing the amount of maize harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of herbicide used on maize (kg)	0.001	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	0.001	0 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Total area of	0.5	0 tCO2e per	0	0		Unknown

maize (ha)		ha				
Amount of herbicide used on wheat (kg)	0.002	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Total area of wheat (ha)	1	0 tCO2e per ha	0	0		Unknown
Amount of fungicide used on wheat (kg)	0.001	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat sprayed with pesticides (liquids) (ha)	0.5	0 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.

A3.2. Gödöllő, Szárítópuszta, Hungary (cereals and oilseeds)

Description:

Enterprises:	• Cereals • Oilseeds
Components:	• Harvest barley • Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (oilseed rape) • Ploughing (wheat) • Prevention of compaction on cultivated land (barley) • Prevention of compaction on cultivated land (oilseed rape) • Prevention of compaction on cultivated land (wheat)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: No • Do not cultivate in poor conditions: No • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: Yes • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Ploughing depth: 20 cm • Rainfall forecasting used: Yes • Rainfall: <600mm • Soil aerator used on compacted areas (cultivated land): Yes

	• Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Sand • Soil type 3: Light sand soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of barley harvested	5 ha
Tonnes of barley harvested	20 t
Area of oilseed rape harvested	5 ha
Tonnes of oilseed rape harvested	10 t
Area of wheat harvested	8 ha
Tonnes of wheat harvested	40 t
Area of barley to which inorganic fertiliser is applied	5 Hectare
Amount of nitrogen applied to barley	0.5 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	5 ha
Amount of nitrogen applied to oilseed rape	0.7 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	8 ha
Amount of nitrogen applied to wheat	0.7 Tonnes of Nitrogen
Amount of insecticide used on barley	0.01 Kilograms of active substance
Amount of herbicide used on barley	0.01 Kilograms of active substance
Amount of fungicide used on barley	0.01 Kilograms of active substance
Amount of insecticide used on oilseed rape	0.01 Kilograms of active substance
Amount of herbicide used on oilseed rape	0.01 Kilograms of active substance
Amount of fungicide used on oilseed rape	0.01 Kilograms of active substance
Amount of fungicide used on wheat	0.01 Kilograms of active substance
Amount of herbicide used on wheat	0.01 Kilograms of active substance
Amount of insecticide used on wheat	0.01 Kilograms of active substance
Area ploughed (barley)	5 ha
Total area of barley	5 ha
Area ploughed (oilseed rape)	5 ha
Total area of oilseed rape	5 ha
Area ploughed (wheat)	8 ha
Total area of wheat	8 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	40 Tonnes	0.122 tCO2e per tonne	0 tCO2 per tonne
Barley	20 Tonnes	0.171 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	10 Tonnes	0.459 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	4.16		Potential negative impact on groundwater quality		<1%-21%
Inorganic fertiliser (oilseed rape)	4.14		Potential negative impact on groundwater quality		<1%-21%
Inorganic fertiliser (barley)	2.97		Potential negative impact on groundwater quality		<1%-15%
Harvesting (wheat)	0.38				<1%
Seedbed preparation/soil management (wheat)	0.35				<1%-3%
Harvesting (barley)	0.23				<1%
Harvesting (oilseed rape)	0.22				<1%
Seedbed preparation/soil management (oilseed rape)	0.22				<1%-2%
Seedbed preparation/soil management (barley)	0.22				<1%-2%
Pesticides (oilseed rape)	0				0%
Pesticides (barley)	0				0%
Pesticides (wheat)	0				0%
Total	**12.88**				**<1%-64%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	53.6		Potential improvements to groundwater quality Potential improvements to groundwater quality		

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture	3.5			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	2.2			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Do not cultivate in poor conditions: Yes	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	1.1			- Wet weather, can cause machinery damage and damage to soil structure.	
Maximum traction efficiency obtained (10-15% wheel slip): No	Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser	0.7			- If maximum traction efficiency is not obtained fuel use will	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	(wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)				increase.	
Straw chopping: No	Harvest barley-Harvest oilseed rape-Harvest wheat	0.5				
Maximum traction efficiency obtained (10-15% wheel slip): Yes	Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.2			- Ensuring maximum traction efficiency will reduce fuel use.	
Driver aids used: Yes	Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.2				
Overpowered tractor not used: Yes	Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.2				
High power to weight ratio tractor used: Yes	Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.2				
Type of inorganic fertiliser: Ammonium nitrate (34.5% N)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser	0.1			- More efficient use of fertilisers will reduce	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	(oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture				emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Vehicles serviced regularly: Yes	Harvest barley-Harvest oilseed rape-Harvest wheat-Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1			- Regularly servicing vehicles will improve fuel efficiency and reliability reducing costly breakdowns. - The cost of servicing should be covered by the savings made from improved efficiency and less repairs.	
Do not cultivate in poor conditions: No	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1			- Wet weather, can cause machinery damage and damage to soil structure.	
Tyres inflated correctly: Yes	Harvest barley-Harvest oilseed rape-Harvest wheat-Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1			- Correct tyre inflation will improve energy efficiency saving fuel and money.	
Ploughing depth: 20 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1			- The deeper the ploughing depth the higher the	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Correct tyres used (reduce rolling resistance): Yes	Harvest barley-Harvest oilseed rape-Harvest wheat-Inorganic fertiliser (barley) application-Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to wheat (t)	0.7	5.94 tCO2e per t	46.1	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	0.5	5.94 tCO2e per t	46	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	0.7	5.93 tCO2e per t	46	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Area of barley harvested (ha)	5	0.05 tCO2e per ha	0.4	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area of wheat harvested (ha)	8	0.05 tCO2e per ha	0.4	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of oilseed rape harvested (ha)	5	0.04 tCO2e per ha	0.3	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Area ploughed (wheat) (ha)	8	0.04 tCO2e per ha	0.3	0		Unknown
Area ploughed (oilseed rape) (ha)	5	0.04 tCO2e per ha	0.3	0		Unknown
Area ploughed (barley) (ha)	5	0.04 tCO2e per ha	0.3	0		Unknown
Tonnes of oilseed rape harvested (tonne)	10	0.02 tCO2e per tonne	0.2	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of barley harvested (tonne)	20	0.01 tCO2e per tonne	0.1	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of wheat harvested (tonne)	40	0.01 tCO2e per tonne	0.1	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of barley to which inorganic fertiliser is applied (ha)	5	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape to which inorganic fertiliser is applied (ha)	5	0 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	8	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Total area of wheat (ha)	8	0 tCO2e per ha	0	0	Potential physical damage to soil	Unknown
Amount of insecticide used on barley (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Total area of barley (ha)	5	0 tCO2e per ha	0	0	Potential physical damage to soil	Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Total area of oilseed rape (ha)	5	0 tCO2e per ha	0	0	Potential physical damage to soil	Unknown
Amount of herbicide used on wheat (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on barley (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on barley (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.

A3.3. Agrár-Béta, Birkamajor, Hungary (cereals, oilseeds and protein crops)

Description:

Enterprises:	• Cereals • Oilseeds • Protein crops
Components:	• Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (maize) application • Inorganic fertiliser (maize) fate • Inorganic fertiliser (maize) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide manufacture (maize) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (maize) • Ploughing (oilseed rape) • Ploughing (wheat) • Prevention of compaction on cultivated land (maize) • Prevention of compaction on cultivated land (oilseed rape) • Prevention of compaction on cultivated land (wheat)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Grid electricity • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: Yes • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Ploughing depth: 20 cm • Rainfall forecasting used: Yes • Rainfall: 600-700mm • Soil aerator used on compacted areas (cultivated land): Yes • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 3: Deep fertile silty soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of oilseed rape harvested	73.2 ha
Tonnes of oilseed rape harvested	250 t
Area of wheat harvested	630.11 ha
Tonnes of wheat harvested	3465 t
Area of maize to which inorganic fertiliser is applied	1289.19 ha
Amount of nitrogen applied to maize	230 Tonnes of Nitrogen

Item	Value
Area of oilseed rape to which inorganic fertiliser is applied	73.2 ha
Amount of nitrogen applied to oilseed rape	9 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	630.11 ha
Amount of nitrogen applied to wheat	130 Tonnes of Nitrogen
Amount of insecticide used on maize	0 Kilograms of active substance
Amount of herbicide used on maize	2 Kilograms of active substance
Amount of fungicide used on maize	0 Kilograms of active substance
Amount of insecticide used on oilseed rape	1 Kilograms of active substance
Amount of herbicide used on oilseed rape	1 Kilograms of active substance
Amount of fungicide used on oilseed rape	1 Kilograms of active substance
Amount of fungicide used on wheat	1 Kilograms of active substance
Amount of herbicide used on wheat	1 Kilograms of active substance
Amount of insecticide used on wheat	0.5 Kilograms of active substance
Area ploughed (maize)	1298.19 ha
Total area of maize	1298.19 ha
Area ploughed (oilseed rape)	73.2 ha
Total area of oilseed rape	73.2 ha
Area ploughed (wheat)	400 ha
Total area of wheat	630.11 ha
Tonnes of maize harvested	9000 t

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	3465 Tonnes	0.259 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	250 Tonnes	0.263 tCO2e per tonne	0 tCO2 per tonne
Maize	9000 Tonnes	0.311 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (maize)	2736.78		Potential negative impact on groundwater quality		<1%-47%
Inorganic fertiliser (wheat)	845.33		Potential negative impact on groundwater quality		<1%-15%
Seedbed preparation/soil management (maize)	65.17				<1%-2%
Inorganic fertiliser (oilseed rape)	58.63		Potential negative impact on groundwater quality		<1%
Harvesting (wheat)	30.39				<1%
Seedbed preparation/soil management (wheat)	20.08				<1%-1%
Seedbed preparation/soil	3.67				<1%

management (oilseed rape)					
Harvesting (oilseed rape)	3.34				0%
Pesticides (oilseed rape)	0.09				0%
Pesticides (wheat)	0.07				0%
Pesticides (maize)	0.07				0%
Total	**3763.61**				**<1%-66%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (maize) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	59.2		Potential improvements to groundwater quality Potential improvements to groundwater quality		
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (maize) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture	4			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Ploughing depth: 15 cm	Ploughing (maize)-Ploughing (oilseed rape)-Ploughing (wheat)	0.9			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Straw chopping: No	Harvest wheat	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to maize (t)	230	11.9 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	9	6.51 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	130	6.5 tCO2e per t	0.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area of wheat to which inorganic fertiliser is applied (ha)	630.11	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Total area of wheat (ha)	630.11	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape to which inorganic fertiliser is applied (ha)	73.2	0 tCO2e per ha	0	0		Unknown
Tonnes of maize harvested (tonne)	9000	0 tCO2e per tonne	0	0		Reducing the amount of maize harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of maize to which inorganic fertiliser is	1289.19	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on maize yields. Review N use

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
applied (ha)						practices to ensure they are optimal and match crop requirements.
Tonnes of oilseed rape harvested (tonne)	250	0.01 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	630.11	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Tonnes of wheat harvested (tonne)	3465	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of herbicide used on maize (kg)	2	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on oilseed rape (kg)	1	0.09 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	1	0.09 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Total area of oilseed rape (ha)	73.2	0 tCO2e per ha	0	0		Unknown
Area ploughed (wheat) (ha)	400	0.05 tCO2e per ha	0	0		Unknown
Total area of maize (ha)	1298.19	0 tCO2e per ha	0	0		Unknown
Area ploughed (oilseed rape) (ha)	73.2	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (maize) (ha)	1298.19	0.05 tCO2e per ha	0	0		Unknown
Amount of fungicide used on oilseed rape (kg)	1	0.09 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	1	0.07 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on wheat (kg)	1	0.07 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of insecticide used on wheat (kg)	0.5	0.14 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape harvested (ha)	73.2	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.

A3.4. Lovasberény, Hungary (cattle, pigs, cereals, oilseeds and protein crops)

Description:

Enterprises:	• Cattle fattening • Cereals • Oilseeds • Pig fattening • Protein crops
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Harvest barley • Harvest oilseed rape • Harvest triticale • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (maize) application • Inorganic fertiliser (maize) fate • Inorganic fertiliser (maize) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (triticale) application • Inorganic fertiliser (triticale) fate • Inorganic fertiliser (triticale) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide manufacture (barley) • Pesticide manufacture (maize) • Pesticide manufacture (triticale) • Pesticide manufacture (wheat) • Ploughing (maize) • Ploughing (oilseed rape) • Prevention of compaction on cultivated land (barley) • Prevention of compaction on cultivated land (maize) • Prevention of compaction on cultivated land (oilseed rape) • Prevention of compaction on cultivated land (triticale) • Prevention of compaction on cultivated land (wheat) • Prevention of compaction on grassland
Modifiers:	• Archaeological features: No archaeological features • Beef cattle diet: H. 3874 kgDM grazing • Beef cattle production system: Lowland suckler cattle herd (autumn calving) • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes

	• Energy/fuel source (Production of inorganic N fertiliser): Grid electricity • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • Feeding troughs moved frequently: Yes (or n.a.) • Grassland not entered with heavy machinery when wet: Yes • High power to weight ratio tractor used: Yes • Location: Southern Europe • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): Yes • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Ploughing depth: 20 cm • Rainfall forecasting used: No • Rainfall: 600-700mm • Soil aerator used on compacted areas (cultivated land): Yes • Soil aerator used on compacted areas (grassland): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 3: Deep fertile silty soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Number of beef cattle	260
Percentage of year beef cattle are housed	60 Percentage (0 to 100)
Area of grassland	135 ha
Area of barley harvested	170 ha
Tonnes of barley harvested	765 t
Area of oilseed rape harvested	60 ha
Tonnes of oilseed rape harvested	180 t
Area of triticale harvested	10 ha
Tonnes of triticale harvested	50 t
Area of wheat harvested	421 ha
Tonnes of wheat harvested	2315 t
Area of barley to which inorganic fertiliser is applied	170 Hectare
Amount of nitrogen applied to barley	20 Tonnes of Nitrogen
Area of maize to which inorganic fertiliser is applied	540 ha
Amount of nitrogen applied to maize	95 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	60 ha
Amount of nitrogen applied to oilseed rape	6.5 Tonnes of Nitrogen
Area of triticale to which inorganic fertiliser is applied	10 ha
Amount of nitrogen applied to triticale	1.5 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	421 ha
Amount of nitrogen applied to wheat	60 Tonnes of Nitrogen
Amount of insecticide used on barley	0 Kilograms of active substance
Amount of herbicide used on barley	2 Kilograms of active substance
Amount of fungicide used on barley	1 Kilograms of active substance
Amount of insecticide used on maize	0 Kilograms of active substance

Item	Value
Amount of herbicide used on maize	3 Kilograms of active substance
Amount of fungicide used on maize	0 Kilograms of active substance
Amount of insecticide used on triticale	0 Kilograms of active substance
Amount of herbicide used on triticale	0.1 Kilograms of active substance
Amount of fungicide used on triticale	0.1 Kilograms of active substance
Amount of fungicide used on wheat	3 Kilograms of active substance
Amount of herbicide used on wheat	3 Kilograms of active substance
Amount of insecticide used on wheat	1 Kilograms of active substance
Total area of barley	170 ha
Area ploughed (maize)	540 ha
Total area of maize	540 ha
Area ploughed (oilseed rape)	60 ha
Total area of oilseed rape	60 ha
Total area of triticale	10 ha
Total area of wheat	421 ha
Tonnes of beef output	30 Tonnes Live Weight
Tonnes of maize harvested	3780 t

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	2315 Tonnes	0.185 tCO2e per tonne	0 tCO2 per tonne
Barley	765 Tonnes	0.189 tCO2e per tonne	0 tCO2 per tonne
Triticale	50 Tonnes	0.214 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	180 Tonnes	0.278 tCO2e per tonne	0 tCO2 per tonne
Maize	3780 Tonnes	0.321 tCO2e per tonne	0 tCO2 per tonne
Beef	30 Tonnes Live Weight	15.118 tCO2e per t LW	0 tCO2 per t LW

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (maize)	1187.05		Potential negative impact on groundwater quality		<1%-35%
Beef cattle	453.56				<1%-2%
Inorganic fertiliser (wheat)	408.5		Potential negative impact on groundwater quality		<1%-12%
Inorganic fertiliser (barley)	136.27		Potential negative impact on groundwater quality		<1%-4%
Inorganic fertiliser (oilseed rape)	44.31		Potential negative impact on groundwater quality		<1%
Seedbed preparation/soil management (maize)	27.11				<1%-1%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Harvesting (wheat)	20.3				<1%
Inorganic fertiliser (triticale)	10.21		Potential negative impact on groundwater quality		<1%
Harvesting (barley)	7.99				<1%
Seedbed preparation/soil management (oilseed rape)	3.01				<1%
Harvesting (oilseed rape)	2.71				<1%
Harvesting (triticale)	0.48				0%
Pesticides (wheat)	0.2				0%
Pesticides (maize)	0.1				0%
Pesticides (barley)	0.09				0%
Pesticides (triticale)	0.01				0%
Grassland management	0				0%
Seedbed preparation/soil management (triticale)	0				0%
Seedbed preparation/soil management (barley)	0				0%
Seedbed preparation/soil management (wheat)	0				0%
Total	**2301.89**				**<1%-55%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (maize) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (triticale) fate-Inorganic fertiliser (wheat) fate	47.5		Potential improvements to groundwater quality Potential improvements to groundwater quality Potential improvements to groundwater quality		
Rainfall forecasting used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser	3.6				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	(maize) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (triticale) fate-Inorganic fertiliser (wheat) fate					
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (maize) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture	3.2			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.6				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.5				
Beef cattle diet: C. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM lucerne silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.7				
Beef cattle diet: G. 2411 kgDM grazing; 415 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.7				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Ploughing depth: 15 cm	Ploughing (maize)-Ploughing (oilseed rape)	0.5			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Beef cattle diet: A. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.5				
Beef cattle diet: E. 2411 kgDM grazing; 1263 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.4				
Beef cattle diet: F. 1929 kgDM grazing; 482 kg DM clover; 115 kgDM grass hay average; 1148 kgDM grass silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.2				
Straw chopping: No	Harvest barley-Harvest oilseed rape-Harvest wheat	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to maize (t)	95	12.5 tCO2e per t	0.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to triticale (t)	1.5	6.81 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	20	6.81 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	60	6.81 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	6.5	6.82 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Number of beef cattle (head)	260	1.74 tCO2e per head	0.1	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Area ploughed (maize) (ha)	540	0.05 tCO2e per ha	0	0		Unknown
Area of barley to which inorganic fertiliser is applied (ha)	170	0 tCO2e per ha	0	0		Unknown
Tonnes of wheat harvested (tonne)	2315	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Total area of triticale (ha)	10	0 tCO2e per ha	0	0		Unknown
Tonnes of triticale harvested (tonne)	50	0.01 tCO2e per tonne	0	0		Reducing the amount of triticale harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of maize to which inorganic fertiliser is applied (ha)	540	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of wheat harvested (ha)	421	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
						increase.
Area of triticale harvested (ha)	10	0.05 tCO2e per ha	0	0		Reducing the area of triticale may decrease total yield unless yields per hectare increase.
Total area of barley (ha)	170	0 tCO2e per ha	0	0		Unknown
Area of barley harvested (ha)	170	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Area of grassland (ha)	135	0 tCO2e per ha	0	0		Unknown
Tonnes of barley harvested (tonne)	765	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of oilseed rape harvested (tonne)	180	0.02 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape harvested (ha)	60	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Total area of oilseed rape (ha)	60	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape to which inorganic fertiliser is applied (ha)	60	0 tCO2e per ha	0	0		Unknown
Area ploughed (oilseed rape) (ha)	60	0.05 tCO2e per ha	0	0		Unknown
Amount of fungicide used on wheat (kg)	3	0.07 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on triticale (kg)	0.1	0.1 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on wheat (kg)	3	0.07 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of triticale to which inorganic fertiliser is applied (ha)	10	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on triticale yields. Review N use practices to ensure they are optimal and match crop

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
						requirements.
Amount of insecticide used on wheat (kg)	1	0.2 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on triticale (kg)	0.1	0.1 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce triticale yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on maize (kg)	3	0.03 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on barley (kg)	1	0.09 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on barley (kg)	2	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Total area of wheat (ha)	421	0 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	421	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Total area of maize (ha)	540	0 tCO2e per ha	0	0		Unknown
Tonnes of maize harvested (tonne)	3780	0 tCO2e per tonne	0	0		Reducing the amount of maize harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Percentage of year beef cattle are housed (%)	60	-2.51 tCO2e per %	-0.1	0		Unknown

A3.5. Karcsa, Hungary (cereals and oilseeds)

Description:

Enterprises:	• Cereals • Oilseeds
Components:	• Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (oilseed rape) • Prevention of compaction on cultivated land (oilseed rape) • Prevention of compaction on cultivated land (wheat)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Do not cultivate in poor conditions: Yes • Driver aids used: No • Energy/fuel source (Production of inorganic N fertiliser): Grid electricity • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: Yes • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Ploughing depth: 15 cm • Rainfall forecasting used: No • Rainfall: <600mm • Soil aerator used on compacted areas (cultivated land): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Clay • Soil type 3: Medium and deep clay soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of oilseed rape harvested	11.5 ha
Tonnes of oilseed rape harvested	29 t
Area of wheat harvested	10 ha
Tonnes of wheat harvested	55 t
Area of oilseed rape to which inorganic fertiliser is applied	11.5 ha
Amount of nitrogen applied to oilseed rape	1 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	10 ha
Amount of nitrogen applied to wheat	1.5 Tonnes of Nitrogen
Amount of insecticide used on oilseed rape	0.01 Kilograms of active substance
Amount of herbicide used on oilseed rape	0.01 Kilograms of active substance
Amount of fungicide used on oilseed rape	0.01 Kilograms of active substance
Amount of fungicide used on wheat	0.01 Kilograms of active substance

Item	Value
Amount of herbicide used on wheat	0.01 Kilograms of active substance
Amount of insecticide used on wheat	0 Kilograms of active substance
Area ploughed (oilseed rape)	11.5 ha
Total area of oilseed rape	11.5 ha
Total area of wheat	10 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	55 Tonnes	0.229 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	29 Tonnes	0.336 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	12.09		Potential negative impact on groundwater quality		<1%-36%
Inorganic fertiliser (oilseed rape)	8.08		Potential negative impact on groundwater quality		<1%-24%
Seedbed preparation/soil management (oilseed rape)	1.14				<1%-5%
Harvesting (oilseed rape)	0.51				<1%
Harvesting (wheat)	0.48				<1%
Pesticides (oilseed rape)	0				0%
Pesticides (wheat)	0				0%
Seedbed preparation/soil management (wheat)	0				0%
Total	**22.3**				**<1%-66%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	54.4		Potential improvements to groundwater quality		
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture	4.5			- More efficient use of fertilisers will reduce emissions and save money.	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Rainfall forecasting used: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	4.3				
Straw chopping: No	Harvest oilseed rape-Harvest wheat	0.3				
Driver aids used: Yes	Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Ploughing (oilseed rape)	0.2				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to oilseed rape (t)	1	8.08 tCO2e per t	36.2	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	1.5	8.06 tCO2e per t	36.1	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area ploughed (oilseed rape) (ha)	11.5	0.1 tCO2e per ha	0.4	0		Unknown
Area of wheat harvested (ha)	10	0.05 tCO2e per ha	0.2	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of oilseed rape harvested (ha)	11.5	0.04 tCO2e per ha	0.2	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Tonnes of oilseed rape harvested (tonne)	29	0.02 tCO2e per tonne	0.1	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of herbicide used on wheat (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	11.5	0 tCO2e per ha	0	0		Unknown
Tonnes of wheat harvested (tonne)	55	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of fungicide used on wheat (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on oilseed rape (kg)	0.01	0 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Total area of oilseed rape (ha)	11.5	0 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	10	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Total area of wheat (ha)	10	0 tCO2e per ha	0	0		Unknown

A4. Italy

A4.1. Via Abbazia, Campagnola Emilia, Italy (pigs)

Description:

Enterprises:	• Pig fattening • Pig rearing
Components:	• Indoor breeding unit heating, lighting and ventilation • Indoor finishers (heavy) heating, lighting and ventilation • Indoor weaners heating, lighting and ventilation
Modifiers:	• Correct siting and accurate temperature sensors: No • Enclosed creep, heater lamp automatic control and dimmer switches: No • Energy/fuel source (Buildings): Grid electricity • Ensure insulation always dry: No • Fans interlinked to heaters (heaters on only when fans low): No • Insulated enclosed creep: No • Lying area panels on flat decks: No • Pig housing - Low energy lighting: Yes • Pig housing ventilation - Fan and ventilation functioning optimally and openings checked frequently for obstructions: Yes • Pig housing ventilation - Flat deck with correct number of fans : Yes • Pig indoor breeding unit size: Medium (1200 to 2100 head) • Pig Indoor finishers (heavy) unit size: Large (over 2100 head) • Pig indoor weaners unit size: Large (over 2100 head) • Under floor heating, heated pads: No

Item	Value
Number of pigs (Indoor breeding unit)	450
Percentage of year pigs (indoor breeding) unit is occupied	90 Percentage (0 to 100)
Number of pigs (Indoor finishers - heavy)	4000
Percentage of year pigs (indoor finishers - heavy) unit is occupied	80 Percentage (0 to 100)
Number of pigs (Indoor weaners)	2800
Percentage of year pigs (indoor weaners) unit is occupied	80 Percentage (0 to 100)

Results summary:

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Indoor finishers (heavy)	24				<1%-48%
Indoor weaners	16.8				<1%-34%
Indoor breeding unit	3.04				<1%-6%
Total	**43.84**				**<1%-88%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Fans interlinked to heaters (heaters on only when fans low): Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	57.3				
Under floor heating, heated pads: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	40				
Enclosed creep, heater lamp automatic control and dimmer switches: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	33.3				
Correct siting and accurate temperature sensors: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	9.3				
Ensure insulation always dry: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	6.7				
Insulated enclosed creep: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and	6.7				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	ventilation					
Lying area panels on flat decks: Yes	Indoor breeding unit heating, lighting and ventilation-Indoor finishers (heavy) heating, lighting and ventilation-Indoor weaners heating, lighting and ventilation	4				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Percentage of year pigs (indoor finishers - heavy) unit is occupied (%)	80	0.3 tCO2e per %	0.7	0		Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Percentage of year pigs (indoor weaners) unit is occupied (%)	80	0.21 tCO2e per %	0.5	0		Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Percentage of year pigs (indoor breeding) unit is occupied (%)	90	0.03 tCO2e per %	0.1	0		Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Number of pigs (Indoor finishers - heavy) (head)	4000	0.01 tCO2e per head	0	0		Reducing the number of pigs will directly reduce output unless output per pig can be increased.
Number of pigs (Indoor weaners) (head)	2800	0.01 tCO2e per head	0	0		Reducing the number of pigs will directly reduce output unless output per pig can be increased.
Number of pigs (Indoor breeding unit) (head)	450	0.01 tCO2e per head	0	0		Reducing the number of pigs will directly reduce output unless output per pig can be increased.

A4.2. Ghiardo Di Bibbiano, Reggio Emilia, Italy (dairy)

Description:

Enterprises:	• Dairy (milk)
Components:	• Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy lighting • Dairy manure storage • Dairy slurry storage • Load manure (grassland) • Milk plant cleaning • Milking machine (milking) • Mowing • Rake • Solid manure (grassland) application • Solid manure (grassland) fate • Udder washing
Modifiers:	• Automatic lighting controls: No • Correct thermostat setting and regular checks for leaks: Yes • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: H. 1559 kgDM grazing; 390 kgDM lucerne fresh; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Dairy cow dietary additives used: No • Dairy cow improved breed: Yes • Dairy herd size: Large (> 140 head) • Dairy manure store: Solid storage (unconfined piles or stacks) • Dairy manure temperature: Unknown • Dairy slurry store: Liquid/Slurry with natural crust cover • Dairy slurry temperature: Unknown • Distance between dairy manure stores and surface water or drains: Greater than 10 metres • Driver aids used: No • Energy/fuel source (Buildings): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • Heat recovery system to recycle heat removed from milk to heat wash water: No • High power to weight ratio tractor used: No • Location: Southern Europe • Low energy lighting: No • Manure application technique: Surface application • Manure application timing: Spring • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Overpowered tractor not used: Yes • Rainfall: 600-700mm • Soil type 2: Organomineral • Soil type 4: Heavy / medium • Types of manure applied: Cattle FYM - old • Types of mower: Mower-conditioner • Types of rake: Tedder rake • Tyres inflated correctly: Yes • Vacuum pump with variable speed controls: No • Vehicles serviced regularly: Yes • Wash system: Cold wash (using cleaning chemicals)

Item	Value
Number of dairy cattle	490
Percentage of year dairy cattle are housed	100 Percentage (0 to 100)
Area of grassland cut	235 ha
Number of times per year that the grass is cut	4
Amount of cattle FYM (old) applied to grassland	6000 t
Area of grassland to which solid manure is applied	235 ha
Thousands of litres of milk produced per year	2600 Thousand litres (farm total)

Results summary:

Output	Quantity	Emissions	Sequestration
Milk	2600 Thousand litres (farm total)	1.236 tCO2e per thousand litres	0.001 tCO2 per thousand litres

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Dairy cow	2555.48				<1%-43%
Solid manure applications (grassland)	594.73	2.55 (for 248 years)			<1%-1%
Dairy building	32.19				<1%
Grassland management	30.83				<1%
Total	**3213.24**	**2.55**			**<1%-45%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Dairy slurry store: Anaerobic digestion	Dairy slurry storage	30.1		Potential improvements to air quality	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Dairy slurry store: Liquid Aerobic treatment - forced aeration	Dairy slurry storage	20.5		Potential decrease in air quality	- New slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					means better use of nutrients.	
Dairy slurry store: Liquid Aerobic treatment - natural aeration	Dairy slurry storage	15.2		Potential decrease in air quality	- New slurry store may cost typically between €10 and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	8.2				
Dairy slurry temperature: <10 C	Dairy slurry storage	8.5		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Dairy cow diet: K. 1949 kgDM grazing; 1839 kgDM grass silage average; 585 kgDM maize silage; 2414 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	4.4				
Dairy slurry temperature: 12 C	Dairy slurry storage	4.8		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley;	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	4.3				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
20% rapeseed meal)						
Dairy cow diet: D. 1949 kgDM grazing; 585 kgDM maize silage; 2339 wheat whole crop fermented; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	4.2				
Dairy cow diet: C. 1949 kgDM grazing; 585 kgDM maize silage; 2339 lucerne silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	3.4				
Dairy cow diet: E. 1949 kgDM grazing; 2339 kgDM grass hay average; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	3.3				
Dairy manure store: Composting - in-vessel (forced aeration and continuous mixing)	Dairy manure storage	3.2				
Dairy manure store: Composting - static pile (forced aeration)	Dairy manure storage	3.2				
Dairy cow dietary additives used: Yes	Dairy cow enteric fermentation	1.5				
Dairy cow diet: I. 1559 kgDM grazing; 390 kgDM fodder beet; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage-Dairy slurry storage	0.4				
Driver aids used: Yes	Mowing-Rake-Solid manure (grassland) application	0.4				
Types of mower: Mower	Mowing	0.2				
Vacuum pump with variable speed controls: Yes	Milk plant cleaning-Milking machine (milking)	0.2				
Manure application technique: Soil incorporated (24 hours)	Solid manure (grassland) fate	0.2	2.55			
High power to weight ratio tractor used: Yes	Mowing-Rake-Solid manure (grassland)	0.2				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	application				⭐	

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Percentage of year dairy cattle are housed (%)	100	13.97 tCO2e per %	0.4	0		Unknown
Number of dairy cattle (head)	490	5.28 tCO2e per head	0.2	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Number of times per year that the grass is cut (Number)	4	7.71 tCO2e per Number	0.2	0		Unknown
Area of grassland to which solid manure is applied (ha)	235	0.94 tCO2e per ha	0	0.01		Unknown
Amount of cattle FYM (old) applied to grassland (tonne)	6000	0.1 tCO2e per tonne	0	0		Unknown
Area of grassland cut (ha)	235	0.13 tCO2e per ha	0	0		Unknown

A5. Poland

A5.1. Wisznia Mala Farm, Wroclaw, Poland (cereals, oilseeds and root crops)

Description:

Enterprises:	• Cereals • Oilseeds • Root crops
Components:	• Drying rape seed • Harrow (potatoes) • Harvest barley • Harvest oilseed rape • Harvest potatoes • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (potatoes) application • Inorganic fertiliser (potatoes) fate • Inorganic fertiliser (potatoes) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide application - liquids (barley) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (potatoes) • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (potatoes) • Pesticide manufacture (wheat) • Planting (potatoes) • Ploughing (barley) • Ploughing (oilseed rape) • Ploughing (potatoes) • Ploughing (wheat) • Ridging (potatoes) • Rolling (wheat)
Modifiers:	• Archaeological features: Some archaeological features (moderate value, some legal protection) • Correct tyres used (reduce rolling resistance): Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Machinery): Gas/diesel oil • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: Yes • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 20 cm • Rainfall forecasting used: Yes • Rainfall: >700mm • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 3: Light sand soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N)

	• Types of harrow: Rotary cultivator (4 m) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of barley harvested	40 ha
Tonnes of barley harvested	300 t
Area of oilseed rape harvested	20 ha
Tonnes of oilseed rape harvested	70 t
Area of potatoes harvested	10 ha
Tonnes of potatoes harvested	400 t
Area of wheat harvested	55 ha
Tonnes of wheat harvested	330 t
Area of barley to which inorganic fertiliser is applied	40 Hectare
Amount of nitrogen applied to barley	3.2 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	20 ha
Amount of nitrogen applied to oilseed rape	3.6 Tonnes of Nitrogen
Area of potatoes to which inorganic fertiliser is applied	10 ha
Amount of nitrogen applied to potatoes	1.3 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	55 ha
Amount of nitrogen applied to wheat	8.25 Tonnes of Nitrogen
Area of barley sprayed with pesticides (liquids)	40 ha
Amount of insecticide used on barley	50 Kilograms of active substance
Amount of herbicide used on barley	50 Kilograms of active substance
Amount of fungicide used on barley	60 Kilograms of active substance
Area of oilseed rape sprayed with pesticides (liquids)	20 ha
Amount of insecticide used on oilseed rape	50 Kilograms of active substance
Amount of herbicide used on oilseed rape	50 Kilograms of active substance
Amount of fungicide used on oilseed rape	40 Kilograms of active substance
Area of potatoes sprayed with pesticides (liquids)	10 ha
Amount of insecticide used on potatoes	50 Kilograms of active substance
Amount of herbicide used on potatoes	50 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	55 ha
Amount of fungicide used on wheat	100 Kilograms of active substance
Amount of herbicide used on wheat	100 Kilograms of active substance
Amount of insecticide used on wheat	75 Kilograms of active substance
Area ploughed (barley)	40 ha
Area ploughed (oilseed rape)	20 ha
Area harrowed (potatoes)	10 ha
Area planted (potatoes)	10 ha
Area ploughed (potatoes)	10 ha
Area ridged (potatoes)	10 ha
Area ploughed (wheat)	55 ha

Item	Value
Area rolled (wheat)	55 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	330 Tonnes	0.199 tCO2e per tonne	0 tCO2 per tonne
Barley	300 Tonnes	0.094 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	70 Tonnes	0.409 tCO2e per tonne	0 tCO2 per tonne
Potatoes	400 Tonnes	0.048 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	55.01		Potential negative impact on groundwater quality		<1%-25%
Inorganic fertiliser (oilseed rape)	23.99		Potential negative impact on groundwater quality		<1%-11%
Inorganic fertiliser (barley)	21.41		Potential negative impact on groundwater quality		<1%-10%
Inorganic fertiliser (potatoes)	11.04		Potential negative impact on groundwater quality		<1%-5%
Pesticides (wheat)	4.08				<1%
Seedbed preparation/soil management (wheat)	3.85		Potential negative impact on archaeological sites and features		<1%-2%
Harvesting (potatoes)	3.59				0%
Harvesting (wheat)	2.69				<1%
Pesticides (barley)	2.45				<1%
Seedbed preparation/soil management (potatoes)	2.37		Potential negative impact on archaeological sites and features		<1%-1%
Seedbed preparation/soil management (barley)	2.31		Potential negative impact on archaeological sites and features		<1%-2%
Pesticides (potatoes)	2.15				0%
Pesticides (oilseed rape)	2.07				<1%
Harvesting (barley)	2.03				<1%
Seedbed preparation/soil management (oilseed rape)	1.16		Potential negative impact on archaeological sites and features		<1%-1%
Harvesting (oilseed rape)	0.91				<1%
Product drying (oilseeds)	0.49				0%
Total	**141.6**				**<1%-57%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO_2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (potatoes) fate-Inorganic fertiliser (wheat) fate	48.6		Potential improvements to groundwater quality Potential decrease in groundwater quality		
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (potatoes) manufacture-Inorganic fertiliser (wheat) manufacture	2.7			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (potatoes)-Ploughing (wheat)	2		Potential decrease in damage to archaeological sites and features Potential decrease in damage to archaeological sites and features Potential increase in damage to archaeological sites and features	- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Overpowered tractor not	Inorganic fertiliser	1				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
used: Yes	(barley) application-Inorganic fertiliser (wheat) application-Pesticide application - liquids (barley)-Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)-Ploughing (barley)-Ploughing (oilseed rape)-Harrow (potatoes)-Planting (potatoes)-Ploughing (potatoes)-Ridging (potatoes)-Ploughing (wheat)-Rolling (wheat)					
Straw chopping: No	Harvest barley-Harvest oilseed rape-Harvest wheat	0.3				
Types of harrow: Spring tine harrows / weeding	Harrow (potatoes)	0.2				
Types of harrow: Chain harrow	Harrow (potatoes)	0.2				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to potatoes (t)	1.3	8.49 tCO2e per t	6	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on potato yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	3.6	6.66 tCO2e per t	4.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	3.2	6.69 tCO2e per t	4.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	8.25	6.67 tCO2e per t	4.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area of potatoes harvested (ha)	10	0.36 tCO2e per ha	0.3	0		Reducing the area of potatoes may decrease total yield unless yields per hectare increase.
Area of	10	0 tCO2e per	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
potatoes to which inorganic fertiliser is applied (ha)		ha				
Area rolled (wheat) (ha)	55	0.01 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	55	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of barley sprayed with pesticides (liquids) (ha)	40	0.01 tCO2e per ha	0	0		Unknown
Area of oilseed rape to which inorganic fertiliser is applied (ha)	20	0 tCO2e per ha	0	0		Unknown
Area of barley to which inorganic fertiliser is applied (ha)	40	0 tCO2e per ha	0	0		Unknown
Amount of herbicide used on barley (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Tonnes of wheat harvested (tonne)	330	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of barley harvested (tonne)	300	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape harvested (ha)	20	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Tonnes of oilseed rape harvested (tonne)	70	0.02 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of potatoes harvested (tonne)	400	0.01 tCO2e per tonne	0	0		Reducing the amount of potatoes harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat	55	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
harvested (ha)						yields per hectare increase.
Amount of insecticide used on barley (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on barley (kg)	60	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area ploughed (wheat) (ha)	55	0.06 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area harrowed (potatoes) (ha)	10	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (barley) (ha)	40	0.06 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area ploughed (oilseed rape) (ha)	20	0.06 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area planted (potatoes) (ha)	10	0.07 tCO2e per ha	0	0		Unknown
Amount of herbicide used on wheat (kg)	100	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area ploughed (potatoes) (ha)	10	0.06 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area ridged (potatoes) (ha)	10	0.06 tCO2e per ha	0	0		Unknown
Amount of insecticide used on wheat (kg)	75	0.05 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	100	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape sprayed with pesticides (liquids) (ha)	20	0.01 tCO2e per ha	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of fungicide used on oilseed rape (kg)	40	0.05 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on oilseed rape (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of potatoes sprayed with pesticides (liquids) (ha)	10	0.01 tCO2e per ha	0	0		Unknown
Area of wheat sprayed with pesticides (liquids) (ha)	55	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of insecticide used on potatoes (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce potato yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on potatoes (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce potato yields. Review the pesticide use strategy to ensure it is optimal.
Area of barley harvested (ha)	40	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.

A5.2. Ligota Piekna, Poland (cereals, oilseeds and root crops)

Description:

Enterprises:	• Cereals • Oilseeds • Root crops
Components:	• Drilling (wheat) • Harrow (oilseed rape) • Harrow (wheat) • Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (wheat) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (oilseed rape) • Ploughing (wheat)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: No • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 25 cm • Rainfall forecasting used: Yes • Rainfall: <600mm • Soil Nitrogen Supply (SNS) known: No • Soil type 1: Loam • Soil type 3: Medium and deep clay soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of drill: Combined harrow and drill • Types of harrow: Power harrow • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of oilseed rape harvested	20 ha
Tonnes of oilseed rape harvested	60 t
Area of wheat harvested	30 ha
Tonnes of wheat harvested	180 t
Area of oilseed rape to which inorganic fertiliser is applied	20 ha
Amount of nitrogen applied to oilseed rape	3 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	30 ha
Amount of nitrogen applied to wheat	4 Tonnes of Nitrogen

Item	Value
Area of oilseed rape sprayed with pesticides (liquids)	20 ha
Amount of insecticide used on oilseed rape	2 Kilograms of active substance
Amount of herbicide used on oilseed rape	2 Kilograms of active substance
Amount of fungicide used on oilseed rape	2 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	30 ha
Amount of fungicide used on wheat	3 Kilograms of active substance
Amount of herbicide used on wheat	3 Kilograms of active substance
Amount of insecticide used on wheat	3 Kilograms of active substance
Area harrowed (oilseed rape)	20 ha
Area ploughed (oilseed rape)	20 ha
Area drilled (wheat)	30 ha
Area harrowed (wheat)	30 ha
Area ploughed (wheat)	30 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	180 Tonnes	0.226 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	60 Tonnes	0.471 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	32.53		Potential negative impact on groundwater quality		<1%-32%
Inorganic fertiliser (oilseed rape)	24.39		Potential negative impact on groundwater quality		<1%-24%
Seedbed preparation/soil management (wheat)	6.45				<1%-8%
Seedbed preparation/soil management (oilseed rape)	2.8				<1%-4%
Harvesting (wheat)	1.47				<1%
Harvesting (oilseed rape)	0.9				<1%
Pesticides (wheat)	0.3				<1%
Pesticides (oilseed rape)	0.2				<1%
Total	**69.03**				**<1%-68%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	51.4		Potential improvements to groundwater quality		
Soil Nitrogen Supply (SNS) known: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	6.9		Potential improvements to groundwater quality	- Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Types of harrow: Spring tine harrows / weeding	Harrow (oilseed rape)-Harrow (wheat)	2.9				
Ploughing depth: 15 cm	Ploughing (oilseed rape)-Ploughing (wheat)	3.3			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Types of harrow: Chain harrow	Harrow (oilseed rape)-Harrow (wheat)	2.8				
Types of drill: Conventional drill	Drilling (wheat)	2.5				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Types of drill: Direct drill	Drilling (wheat)	2.3				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture	2.4			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Overpowered tractor not used: Yes	Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)	1.8				
Ploughing depth: 20 cm	Ploughing (oilseed rape)-Ploughing (wheat)	1.7			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50%	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					higher and cultivations take 40% longer.	
Types of harrow: Rotary cultivator (4 m)	Harrow (oilseed rape)-Harrow (wheat)	0.3				
High power to weight ratio tractor used: Yes	Inorganic fertiliser (oilseed rape) application-Inorganic fertiliser (wheat) application-Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)	0.3				
Straw chopping: No	Harvest oilseed rape-Harvest wheat	0.2				
Pesticide sprayer equipment: Self-propelled sprayer	Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)	0.1			- Self-propelled sprayers are more fuel efficient that tractor and sprayer combinations, so will use less fuel	

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to wheat (t)	4	8.13 tCO2e per t	11.8	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	3	8.13 tCO2e per t	11.8	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of insecticide used on	2	0.04 tCO2e per kg	0.1	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
oilseed rape (kg)						pesticide use strategy to ensure it is optimal.
Area ploughed (wheat) (ha)	30	0.08 tCO2e per ha	0.1	0		Unknown
Amount of fungicide used on oilseed rape (kg)	2	0.04 tCO2e per kg	0.1	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat harvested (ha)	30	0.05 tCO2e per ha	0.1	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area harrowed (wheat) (ha)	30	0.06 tCO2e per ha	0.1	0		Unknown
Amount of herbicide used on oilseed rape (kg)	2	0.04 tCO2e per kg	0.1	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape harvested (ha)	20	0.04 tCO2e per ha	0.1	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Area harrowed (oilseed rape) (ha)	20	0.06 tCO2e per ha	0.1	0		Unknown
Area ploughed (oilseed rape) (ha)	20	0.08 tCO2e per ha	0.1	0		Unknown
Amount of fungicide used on wheat (kg)	3	0.04 tCO2e per kg	0.1	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area drilled (wheat) (ha)	30	0.08 tCO2e per ha	0.1	0		Unknown
Amount of herbicide used on wheat (kg)	3	0.04 tCO2e per kg	0.1	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	3	0.04 tCO2e per kg	0.1	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Tonnes of wheat harvested (tonne)	180	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of oilseed rape harvested (tonne)	60	0.02 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat	30	0.01 tCO2e	0	0		Reducing the area wheat that is

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
sprayed with pesticides (liquids) (ha)		per ha				treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	20	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape sprayed with pesticides (liquids) (ha)	20	0.01 tCO2e per ha	0	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	30	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.

A5.3. Rogozo, Poland (cereals, oilseeds and root crops)

Description:

Enterprises:	• Cereals • Oilseeds • Root crops
Components:	• Discing (wheat) • Drilling (wheat) • Harrow (oilseed rape) • Harrow (potatoes) • Harrow (wheat) • Harvest oilseed rape • Harvest potatoes • Harvest wheat • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (potatoes) application • Inorganic fertiliser (potatoes) fate • Inorganic fertiliser (potatoes) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (potatoes) • Pesticide application - liquids (wheat) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (potatoes) • Pesticide manufacture (wheat) • Planting (potatoes) • Ploughing (oilseed rape) • Ploughing (potatoes) • Ploughing (wheat) • Ridging (potatoes) • Rolling (wheat)

	• Subsoiling (35 cm) (potatoes)
Modifiers:	• Archaeological features: No archaeological features • Correct tyres used (reduce rolling resistance): Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: No • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 25 cm • Rainfall forecasting used: Yes • Rainfall: 600-700mm • Soil Nitrogen Supply (SNS) known: No • Soil type 1: Loam • Soil type 3: Medium and deep clay soils • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Type of sub-soiling: Sub-soiling tramlines only (3 legs) • Types of disc: Disc and pack • Types of drill: Combined harrow and drill • Types of harrow: Rotary cultivator (4 m) • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Area of oilseed rape harvested	50 ha
Tonnes of oilseed rape harvested	150 t
Area of potatoes harvested	10 ha
Tonnes of potatoes harvested	400 t
Area of wheat harvested	125 ha
Tonnes of wheat harvested	750 t
Area of oilseed rape to which inorganic fertiliser is applied	50 ha
Amount of nitrogen applied to oilseed rape	7.5 Tonnes of Nitrogen
Area of potatoes to which inorganic fertiliser is applied	10 ha
Amount of nitrogen applied to potatoes	2 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	125 ha
Amount of nitrogen applied to wheat	21.875 Tonnes of Nitrogen
Area of oilseed rape sprayed with pesticides (liquids)	50 ha
Amount of insecticide used on oilseed rape	20 Kilograms of active substance
Amount of herbicide used on oilseed rape	20 Kilograms of active substance
Amount of fungicide used on oilseed rape	20 Kilograms of active substance
Area of potatoes sprayed with pesticides (liquids)	10 ha
Amount of insecticide used on potatoes	6 Kilograms of active substance
Amount of herbicide used on potatoes	6 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	125 ha
Amount of fungicide used on wheat	50 Kilograms of active substance
Amount of herbicide used on wheat	50 Kilograms of active substance

Item	Value
Amount of insecticide used on wheat	50 Kilograms of active substance
Area harrowed (oilseed rape)	50 ha
Area ploughed (oilseed rape)	50 ha
Area harrowed (potatoes)	10 ha
Area planted (potatoes)	10 ha
Area ploughed (potatoes)	10 ha
Area ridged (potatoes)	10 ha
Area subsoiled (potatoes)	10 ha
Area discing (wheat)	125 ha
Area drilled (wheat)	125 ha
Area harrowed (wheat)	125 ha
Area ploughed (wheat)	125 ha
Area rolled (wheat)	125 ha

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	750 Tonnes	0.28 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	150 Tonnes	0.455 tCO2e per tonne	0 tCO2 per tonne
Potatoes	400 Tonnes	0.069 tCO2e per tonne	0 tCO2 per tonne

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (wheat)	169.25		Potential negative impact on groundwater quality		<1%-37%
Inorganic fertiliser (oilseed rape)	58.06		Potential negative impact on groundwater quality		<1%-13%
Seedbed preparation/soil management (wheat)	31.92				<1%-8%
Inorganic fertiliser (potatoes)	21.13		Potential negative impact on groundwater quality		<1%-5%
Seedbed preparation/soil management (oilseed rape)	6.8				<1%-2%
Harvesting (wheat)	6.11				<1%
Harvesting (potatoes)	3.59				0%
Pesticides (wheat)	2.83				<1%
Seedbed preparation/soil management (potatoes)	2.76				<1%
Harvesting (oilseed rape)	2.26				<1%
Pesticides (oilseed rape)	1.13				<1%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Pesticides (potatoes)	0.31				0%
Total	**306.15**				**<1%-65%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (potatoes) fate-Inorganic fertiliser (wheat) fate	50.4		Potential improvements to groundwater quality Potential decrease in groundwater quality		
Soil Nitrogen Supply (SNS) known: Yes	Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (potatoes) fate-Inorganic fertiliser (wheat) fate	4.4			- Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Ploughing depth: 15 cm	Ploughing (oilseed rape)-Ploughing (potatoes)-Ploughing (wheat)	2.8			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					take 40% longer.	
Types of drill: Conventional drill	Drilling (wheat)	2.4			★★★	
Types of harrow: Spring tine harrows / weeding	Harrow (oilseed rape)-Harrow (potatoes)-Harrow (wheat)	2.1			★★★	
Types of drill: Direct drill	Drilling (wheat)	2.2			★★	
Types of harrow: Chain harrow	Harrow (oilseed rape)-Harrow (potatoes)-Harrow (wheat)	2.1			★★	
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (oilseed rape) manufacture-Inorganic fertiliser (potatoes) manufacture-Inorganic fertiliser (wheat) manufacture	2.4			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Overpowered tractor not used: Yes	Inorganic fertiliser (wheat) application-Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Harrow (potatoes)-Planting (potatoes)-Ploughing (potatoes)-Ridging (potatoes)-Discing (wheat)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Rolling (wheat)	1.8			★	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Ploughing depth: 20 cm	Ploughing (oilseed rape)-Ploughing (potatoes)-Ploughing (wheat)	1.4			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Types of disc: Disc (5.5m)	Discing (wheat)	0.4				
High power to weight ratio tractor used: Yes	Inorganic fertiliser (wheat) application-Pesticide application - liquids (oilseed rape)-Pesticide application - liquids (wheat)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Harrow (potatoes)-Planting (potatoes)-Ploughing (potatoes)-Ridging (potatoes)-Discing (wheat)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Rolling (wheat)	0.3				
Straw chopping: No	Harvest oilseed rape-Harvest wheat	0.2				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to potatoes (t)	2	10.56 tCO2e per t	3.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on potato yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	7.5	7.74 tCO2e per t	2.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	21.875	7.74 tCO2e per t	2.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Area of potatoes harvested (ha)	10	0.36 tCO2e per ha	0.1	0		Reducing the area of potatoes may decrease total yield unless yields per hectare increase.
Amount of herbicide used on oilseed rape (kg)	20	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat to which inorganic fertiliser is applied (ha)	125	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of oilseed rape sprayed with pesticides (liquids) (ha)	50	0.01 tCO2e per ha	0	0		Unknown
Area of potatoes to which inorganic fertiliser is applied (ha)	10	0 tCO2e per ha	0	0		Unknown
Amount of insecticide used on oilseed rape (kg)	20	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area rolled (wheat) (ha)	125	0.01 tCO2e per ha	0	0		Unknown
Area of potatoes sprayed with pesticides (liquids) (ha)	10	0.01 tCO2e per ha	0	0		Unknown
Tonnes of potatoes harvested (tonne)	400	0.01 tCO2e per tonne	0	0		Reducing the amount of potatoes harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Tonnes of oilseed rape	150	0.02 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
harvested (tonne)						economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	125	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	50	0 tCO2e per ha	0	0		Unknown
Tonnes of wheat harvested (tonne)	750	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of fungicide used on oilseed rape (kg)	20	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on potatoes (kg)	6	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce potato yields. Review the pesticide use strategy to ensure it is optimal.
Area ploughed (wheat) (ha)	125	0.08 tCO2e per ha	0	0		Unknown
Area planted (potatoes) (ha)	10	0.07 tCO2e per ha	0	0		Unknown
Area ridged (potatoes) (ha)	10	0.06 tCO2e per ha	0	0		Unknown
Area subsoiled (potatoes) (ha)	10	0.01 tCO2e per ha	0	0		Unknown
Area discing (wheat) (ha)	125	0.03 tCO2e per ha	0	0		Unknown
Area drilled (wheat) (ha)	125	0.08 tCO2e per ha	0	0		Unknown
Area harrowed (wheat) (ha)	125	0.05 tCO2e per ha	0	0		Unknown
Area ploughed (potatoes) (ha)	10	0.08 tCO2e per ha	0	0		Unknown
Area harrowed (potatoes) (ha)	10	0.05 tCO2e per ha	0	0		Unknown
Amount of herbicide used on potatoes (kg)	6	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce potato yields. Review the pesticide use strategy to ensure it is optimal.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area ploughed (oilseed rape) (ha)	50	0.08 tCO2e per ha	0	0		Unknown
Area of wheat sprayed with pesticides (liquids) (ha)	125	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of fungicide used on wheat (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on wheat (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area harrowed (oilseed rape) (ha)	50	0.05 tCO2e per ha	0	0		Unknown
Area of oilseed rape harvested (ha)	50	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.

A5.4. Strseszow, Poland (dairy, cereals and oilseeds)

Description:

Enterprises:	• Cereals • Dairy (milk) • Oilseeds
Components:	• Bailing (barley) • Bailing (wheat) • Dairy cow enteric fermentation • Dairy cow excreta (deposition on pasture) • Dairy lighting • Dairy manure storage • Discing (wheat) • Drilling (wheat) • Harrow (barley) • Harrow (oilseed rape) • Harrow (wheat) • Harvest barley • Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate

	• Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Load manure (barley) • Load manure (wheat) • Milk cooling and storage • Milk plant cleaning • Milking machine (milking) • Pesticide application - liquids (barley) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (oilseed rape) • Ploughing (wheat) • Solid manure (barley) application • Solid manure (barley) fate • Solid manure (wheat) application • Solid manure (wheat) fate • Subsoiling (35 cm) (wheat) • Udder washing
Modifiers:	• Accurate milk tank thermostat: Yes • Archaeological features: Some archaeological features (moderate value, some legal protection) • Automatic lighting controls: No • Correct thermostat setting and regular checks for leaks: Yes • Correct tyres used (reduce rolling resistance): Yes • Dairy cow diet: A. 1949 kgDM grazing; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Dairy cow dietary additives used: Yes • Dairy cow improved breed: No • Dairy herd size: Large (> 140 head) • Dairy manure store: Solid storage (unconfined piles or stacks) • Dairy manure temperature: Unknown • Direct expansion refrigeration bulk tank: No • Distance between dairy manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: No • Driver aids used: Yes • Energy/fuel source (Buildings): Grid electricity • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Heat recovery system to recycle heat removed from milk to heat wash water: Yes • High power to weight ratio tractor used: No • Improved milk tank and pipe insulation: Yes • Location: Northern Europe • Low energy lighting: Yes • Manure application technique: Soil incorporated (24 hours) • Manure application timing: Autumn • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 20 cm • Pre-cool milk before storage tank: No • Rainfall forecasting used: Yes • Rainfall: <600mm • Refrigeration condenser sufficiently ventilated: Yes • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Sand • Soil type 2: Organomineral • Soil type 3: Light sand soils • Soil type 4: Sand • Straw chopping: No

	• Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3) • Type of sub-soiling: Sub-soiling tramlines only (3 legs) • Types of disc: Disc and pack • Types of drill: Combined harrow and drill • Types of harrow: Power harrow • Types of manure applied: Cattle FYM - old • Types of pesticide: Fungicide, Herbicide, Insecticide • Tyres inflated correctly: Yes • Vacuum pump with variable speed controls: No • Vehicles serviced regularly: Yes • Wash system: Hot wash

Item	**Value**
Number of dairy cattle	150
Percentage of year dairy cattle are housed	100 Percentage (0 to 100)
Area of barley harvested	30 ha
Tonnes of barley harvested	5 t
Area of oilseed rape harvested	120 ha
Tonnes of oilseed rape harvested	360 t
Area of wheat harvested	100 ha
Tonnes of wheat harvested	600 t
Area of barley to which inorganic fertiliser is applied	30 Hectare
Amount of nitrogen applied to barley	2.04 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	120 ha
Amount of nitrogen applied to oilseed rape	15.6 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	100 ha
Amount of nitrogen applied to wheat	10.8 Tonnes of Nitrogen
Area of barley sprayed with pesticides (liquids)	30 ha
Amount of insecticide used on barley	12 Kilograms of active substance
Amount of herbicide used on barley	12 Kilograms of active substance
Amount of fungicide used on barley	12 Kilograms of active substance
Area of oilseed rape sprayed with pesticides (liquids)	120 ha
Amount of insecticide used on oilseed rape	50 Kilograms of active substance
Amount of herbicide used on oilseed rape	50 Kilograms of active substance
Amount of fungicide used on oilseed rape	44 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	100 ha
Amount of fungicide used on wheat	40 Kilograms of active substance
Amount of herbicide used on wheat	40 Kilograms of active substance
Amount of insecticide used on wheat	40 Kilograms of active substance
Area harrowed (barley)	30 ha
Area ploughed (barley)	30 ha
Area harrowed (oilseed rape)	120 ha
Area ploughed (oilseed rape)	120 ha
Area discing (wheat)	100 ha
Area drilled (wheat)	100 ha
Area harrowed (wheat)	100 ha

Item	Value
Area ploughed (wheat)	100 ha
Area subsoiled (wheat)	100 ha
Amount of cattle FYM (old) applied to barley	240 t
Area of barley to which solid manure is applied	30 ha
Amount of cattle FYM (old) applied to wheat	800 t
Area of wheat to which solid manure is applied	100 ha
Thousands of litres of milk produced per year	1000 Thousand litres (farm total)

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	600 Tonnes	0.205 tCO2e per tonne	0.001 tCO2 per tonne
Barley	5 Tonnes	8.851 tCO2e per tonne	0.16 tCO2 per tonne
Oilseed rape	360 Tonnes	0.31 tCO2e per tonne	0 tCO2 per tonne
Milk	1000 Thousand litres (farm total)	0.487 tCO2e per thousand litres	0 tCO2 per thousand litres

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Dairy cow	475.66				<1%-15%
Inorganic fertiliser (oilseed rape)	88.8		Potential negative impact on groundwater quality		<1%-7%
Solid manure applications (wheat)	84.98	0.8 (for 792 years)			<1%-1%
Inorganic fertiliser (wheat)	61.55		Potential negative impact on groundwater quality		<1%-5%
Solid manure applications (barley)	25.49	0.8 (for 792 years)			<1%
Seedbed preparation/soil management (wheat)	22.31		Potential negative impact on archaeological sites and features Potential physical improvement to soil		<1%-2%
Dairy building	13.36				<1%-1%
Seedbed preparation/soil management (oilseed rape)	13.02		Potential negative impact on archaeological sites and features		<1%-1%
Inorganic fertiliser (barley)	11.67		Potential negative impact on groundwater quality		<1%-1%
Harvesting (wheat)	7.02				<1%
Harvesting (oilseed rape)	5.02				0%
Seedbed preparation/soil management (barley)	3.26		Potential negative impact on archaeological sites and features		<1%
Pesticides (oilseed rape)	2.72				<1%
Pesticides (wheat)	2.26				0%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Harvesting (barley)	1.9				<1%
Pesticides (barley)	0.68				0%
Total	**819.71**	**1.6**			**<1%-33%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	12.6		Potential improvements to groundwater quality Potential improvements to groundwater quality		
Dairy cow diet: J. 1559 kgDM grazing; 390 kgDM fodder beet; 2924 kgDM maize silage; 1914 kgDM maize flaked	Dairy cow enteric fermentation-Dairy manure storage	5.3				
Dairy cow diet: K. 1949 kgDM grazing; 1839 kgDM grass silage average; 585 kgDM maize silage; 2414 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	4.6				
Dairy manure store: Composting - in-vessel (forced aeration and continuous mixing)	Dairy manure storage	4.4				
Dairy manure store: Composting - static pile (forced aeration)	Dairy manure storage	4.4				
Dairy cow diet: B. 1949 kgDM grazing; 2924 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	3				
Dairy cow diet: D. 1949 kgDM grazing; 585 kgDM maize silage; 2339 wheat whole crop fermented; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	2.8				

Modification	**Components**	**% reduction of total emissions**	**tCO2 sequestration (range)**	**Other impacts (net change)**	**Economic information**	**Data quality**
Dairy cow diet: E. 1949 kgDM grazing; 2339 kgDM grass hay average; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	2.4				
Overpowered tractor not used: Yes	Bailing (barley)-Bailing (wheat)-Pesticide application - liquids (oilseed rape)-Harrow (barley)-Ploughing (barley)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Discing (wheat)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Subsoiling (35 cm) (wheat)-Solid manure (barley) application-Solid manure (wheat) application	1.8				
Types of harrow: Spring tine harrows / weeding	Harrow (barley)-Harrow (oilseed rape)-Harrow (wheat)	1.2				
Types of harrow: Chain harrow	Harrow (barley)-Harrow (oilseed rape)-Harrow (wheat)	1.2				
Dairy cow diet: C. 1949 kgDM grazing; 585 kgDM maize silage; 2339 lucerne silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	1.2				
Types of drill: Conventional drill	Drilling (wheat)	0.7				
Types of drill: Direct drill	Drilling (wheat)	0.6				
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)	0.5		Potential decrease in damage to archaeological sites and features Potential decrease in damage to archaeological	- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
				sites and features	example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Vacuum pump with variable speed controls: Yes	Milk plant cleaning-Milking machine (milking)	0.4				
Dairy cow diet: I. 1559 kgDM grazing; 390 kgDM fodder beet; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	0.4				
Do not cultivate in poor conditions: Yes	Ploughing (barley)-Ploughing (oilseed rape)-Ploughing (wheat)-Subsoiling (35 cm) (wheat)	0.3			- Wet weather, can cause machinery damage and damage to soil structure.	
High power to weight ratio tractor used: Yes	Bailing (barley)-Bailing (wheat)-Pesticide application - liquids (oilseed rape)-Harrow (barley)-Ploughing (barley)-Harrow (oilseed rape)-Ploughing (oilseed rape)-Discing (wheat)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Subsoiling (35 cm) (wheat)-Solid manure (barley) application-Solid manure (wheat) application	0.3				
Types of disc: Disc (5.5m)	Discing (wheat)	0.1				
Pre-cool milk before storage tank: Yes	Milk cooling and storage	0.1				
Types of harrow: Rotary	Harrow (barley)-	0.1				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
cultivator (4 m)	Harrow (oilseed rape)-Harrow (wheat)					
Manure application timing: Spring	Solid manure (wheat) fate	0.1	0.8			
Dairy cow diet: H. 1559 kgDM grazing; 390 kgDM lucerne fresh; 2339 kgDM grass silage; 585 kgDM maize silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Dairy cow enteric fermentation-Dairy manure storage	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to barley (t)	2.04	5.73 tCO2e per t	0.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	10.8	5.7 tCO2e per t	0.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	15.6	5.69 tCO2e per t	0.7	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Number of dairy cattle (head)	150	3.26 tCO2e per head	0.4	0		Reducing the number of dairy cows may decrease total milk yield unless milk yield per cow can be increased.
Percentage of year dairy cattle are housed (%)	100	1.36 tCO2e per %	0.2	0		Unknown
Area of wheat to which inorganic fertiliser is applied (ha)	100	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of barley sprayed with pesticides (liquids) (ha)	30	0.01 tCO2e per ha	0	0		Unknown
Amount of insecticide used on barley (kg)	12	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of herbicide used on barley (kg)	12	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	120	0 tCO2e per ha	0	0		Unknown
Area of barley to which inorganic fertiliser is applied (ha)	30	0 tCO2e per ha	0	0		Unknown
Area of oilseed rape sprayed with pesticides (liquids) (ha)	120	0.01 tCO2e per ha	0	0		Unknown
Tonnes of wheat harvested (tonne)	600	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of barley harvested (ha)	30	0.06 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	5	0.23 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape harvested (ha)	120	0.04 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Tonnes of oilseed rape harvested (tonne)	360	0.01 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	100	0.07 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Amount of fungicide used on barley (kg)	12	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat to which solid manure is applied (ha)	100	0.3 tCO2e per ha	0	0.01		Unknown
Amount of cattle FYM (old) applied to wheat (tonne)	800	0.11 tCO2e per tonne	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area ploughed (wheat) (ha)	100	0.05 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area drilled (wheat) (ha)	100	0.08 tCO2e per ha	0	0		Unknown
Area harrowed (wheat) (ha)	100	0.06 tCO2e per ha	0	0		Unknown
Area subsoiled (wheat) (ha)	100	0.01 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features Potential physical improvement to soil	Unknown
Area ploughed (oilseed rape) (ha)	120	0.05 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Amount of cattle FYM (old) applied to barley (tonne)	240	0.11 tCO2e per tonne	0	0		Unknown
Area of barley to which solid manure is applied (ha)	30	0.3 tCO2e per ha	0	0.03		Unknown
Area discing (wheat) (ha)	100	0.03 tCO2e per ha	0	0		Unknown
Area harrowed (oilseed rape) (ha)	120	0.06 tCO2e per ha	0	0		Unknown
Amount of herbicide used on oilseed rape (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	40	0.04 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on oilseed rape (kg)	44	0.05 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat sprayed with pesticides (liquids) (ha)	100	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
						needed.
Amount of herbicide used on wheat (kg)	40	0.04 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area ploughed (barley) (ha)	30	0.05 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Amount of insecticide used on wheat (kg)	40	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area harrowed (barley) (ha)	30	0.06 tCO2e per ha	0	0		Unknown
Amount of insecticide used on oilseed rape (kg)	50	0.04 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.

A6. Slovenia

A6.1. Šetarova, Lenart V Sloven skih Goricah, Slovenia (cattle, cereals, oilseeds and protein crops)

Description:

Enterprises:	• Cattle fattening • Cereals • Oilseeds • Protein crops
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Beef cattle manure storage • Discing (maize) • Drilling (wheat) • Harrow (barley) • Harrow (maize) • Harrow (wheat) • Harvest barley • Harvest oilseed rape • Harvest wheat • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (grassland) application • Inorganic fertiliser (grassland) fate • Inorganic fertiliser (grassland) manufacture • Inorganic fertiliser (maize) application • Inorganic fertiliser (maize) fate • Inorganic fertiliser (maize) manufacture • Inorganic fertiliser (oilseed rape) application • Inorganic fertiliser (oilseed rape) fate • Inorganic fertiliser (oilseed rape) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Mowing • Pesticide application - liquids (barley) • Pesticide application - liquids (maize) • Pesticide application - liquids (oilseed rape) • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (maize) • Pesticide manufacture (oilseed rape) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (maize) • Ploughing (oilseed rape) • Ploughing (wheat) • Prevention of compaction on cultivated land (barley) • Prevention of compaction on cultivated land (maize) • Prevention of compaction on cultivated land (oilseed rape) • Prevention of compaction on cultivated land (wheat) • Prevention of compaction on grassland • Rolling (barley) • Rolling (wheat) • Slurry (barley) application • Slurry (barley) fate • Slurry (grassland) application • Slurry (grassland) fate • Slurry (maize) application • Slurry (maize) fate • Slurry (oilseed rape) application • Slurry (oilseed rape) fate • Slurry (wheat) application • Slurry (wheat) fate

	• Subsoiling (35 cm) (oilseed rape)
Modifiers:	• Archaeological features: No archaeological features • Beef cattle diet: F. 1929 kgDM grazing; 482 kg DM clover; 115 kgDM grass hay average; 1148 kgDM grass silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Beef cattle manure store: Solid storage (unconfined piles or stacks) • Beef cattle manure temperature: 15 C or Unknown • Beef cattle production system: Lowland suckler cattle herd (autumn calving) • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Distance between beef manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Feeding troughs moved frequently: Yes (or n.a.) • Grassland not entered with heavy machinery when wet: No • High power to weight ratio tractor used: Yes • Location: Southern Europe • Maximum traction efficiency obtained (10-15% wheel slip): No • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 25 cm • Rainfall forecasting used: Yes • Rainfall: >700mm • Slurry application technique: Trailing hose • Slurry application timing: Spring • Slurry incorporation technique: Soil incorporated (6-8 hours) • Soil aerator used on compacted areas (cultivated land): Yes • Soil aerator used on compacted areas (grassland): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Clay • Soil type 3: Medium and deep clay soils • Soil type 4: Heavy / medium • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Type of sub-soiling: Sub-soiling tramlines only (3 legs) • Types of disc: Disc and pack • Types of drill: Combined harrow and drill • Types of harrow: Spring tine harrows / weeding • Types of mower: Mower • Types of pesticide: Fungicide, Herbicide, Insecticide • Types of slurry applied: Beef slurry (6% DM) • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Number of beef cattle	500
Percentage of year beef cattle are housed	0 Percentage (0 to 100)
Area of grassland cut	60 ha
Number of times per year that the grass is cut	4
Area of grassland	60 ha
Area of barley harvested	60 ha
Tonnes of barley harvested	330 t
Area of oilseed rape harvested	120 ha
Tonnes of oilseed rape harvested	420 t
Area of wheat harvested	300 ha

Item	Value
Tonnes of wheat harvested	1800 t
Area of barley to which inorganic fertiliser is applied	60 Hectare
Amount of nitrogen applied to barley	7.5 Tonnes of Nitrogen
Area of grassland to which inorganic fertiliser is applied	60 ha
Amount of nitrogen applied to grassland	14 Tonnes of Nitrogen
Area of maize to which inorganic fertiliser is applied	300 ha
Amount of nitrogen applied to maize	36 Tonnes of Nitrogen
Area of oilseed rape to which inorganic fertiliser is applied	120 ha
Amount of nitrogen applied to oilseed rape	21 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	300 ha
Amount of nitrogen applied to wheat	50 Tonnes of Nitrogen
Area of barley sprayed with pesticides (liquids)	60 ha
Amount of insecticide used on barley	1.2 Kilograms of active substance
Amount of herbicide used on barley	120 Kilograms of active substance
Amount of fungicide used on barley	1.5 Kilograms of active substance
Area of maize sprayed with pesticides (liquids)	300 ha
Amount of insecticide used on maize	6 Kilograms of active substance
Amount of herbicide used on maize	600 Kilograms of active substance
Amount of fungicide used on maize	0 Kilograms of active substance
Area of oilseed rape sprayed with pesticides (liquids)	120 ha
Amount of insecticide used on oilseed rape	3.5 Kilograms of active substance
Amount of herbicide used on oilseed rape	60 Kilograms of active substance
Amount of fungicide used on oilseed rape	3 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	300 ha
Amount of fungicide used on wheat	6 Kilograms of active substance
Amount of herbicide used on wheat	300 Kilograms of active substance
Amount of insecticide used on wheat	6 Kilograms of active substance
Area harrowed (barley)	60 ha
Area ploughed (barley)	60 ha
Total area of barley	60 ha
Area rolled (barley)	60 ha
Area discing (maize)	300 ha
Area harrowed (maize)	300 ha
Area ploughed (maize)	300 ha
Total area of maize	300 ha
Area ploughed (oilseed rape)	120 ha
Total area of oilseed rape	120 ha
Area subsoiled (oilseed rape)	120 ha
Area drilled (wheat)	300 ha
Area harrowed (wheat)	300 ha
Area ploughed (wheat)	300 ha
Total area of wheat	300 ha

Item	Value
Area rolled (wheat)	300 ha
Amount of anaerobically digested beef slurry (6% DM) applied to barley	0 t
Amount of beef slurry (6% DM) applied to barley	900 t
Amount of beef slurry (6% DM) applied to grassland	0 t
Amount of beef slurry (6% DM) applied to maize	5400 t
Amount of beef slurry (6% DM) applied to oilseed rape	2400 t
Amount of beef slurry (6% DM) applied to wheat	0 t
Tonnes of beef output	250 Tonnes Live Weight
Tonnes of maize harvested	15000 t

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	1800 Tonnes	0.256 tCO2e per tonne	0 tCO2 per tonne
Barley	330 Tonnes	0.275 tCO2e per tonne	0 tCO2 per tonne
Oilseed rape	420 Tonnes	0.562 tCO2e per tonne	0 tCO2 per tonne
Maize	15000 Tonnes	0.044 tCO2e per tonne	0 tCO2 per tonne
Beef	250 Tonnes Live Weight	5.637 tCO2e per t LW	0 tCO2 per t LW

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Beef cattle	1216.66				<1%-5%
Inorganic fertiliser (maize)	457.09		Potential negative impact on groundwater quality		<1%-10%
Inorganic fertiliser (wheat)	369.11		Potential negative impact on groundwater quality		<1%-8%
Inorganic fertiliser (grassland)	188.35		Potential negative impact on groundwater quality		<1%
Inorganic fertiliser (oilseed rape)	155		Potential negative impact on groundwater quality		<1%-4%
Slurry applications (maize)	126.91		Potential negative impact on air quality		<1%-3%
Seedbed preparation/soil management (wheat)	71.31				<1%-2%
Seedbed preparation/soil management (maize)	63.72				<1%-2%
Slurry applications (oilseed rape)	56.4		Potential negative impact on air quality		<1%-1%
Inorganic fertiliser (barley)	55.43		Potential negative impact on groundwater quality		<1%
Slurry applications (barley)	21.15		Potential negative impact on air quality		<1%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Seedbed preparation/soil management (oilseed rape)	17.41				<1%-1%
Harvesting (wheat)	14.66				<1%
Seedbed preparation/soil management (barley)	9.51				<1%
Pesticides (maize)	9.16				0%
Pesticides (wheat)	5.64				0%
Harvesting (oilseed rape)	5.49				<1%
Grassland management	4.28		Potential physical damage to soil		<1%
Harvesting (barley)	2.89				<1%
Pesticides (barley)	1.85				0%
Pesticides (oilseed rape)	1.56				0%
Slurry applications (grassland)	0				0%
Slurry applications (wheat)	0				0%
Total	**2853.6**				**<1%-38%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (maize) fate-Inorganic fertiliser (oilseed rape) fate-Inorganic fertiliser (wheat) fate	22.7		Potential improvements to groundwater quality Potential decrease in groundwater quality		
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	5.3				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60% wheatfeed; 20% barley;	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	5.1				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
20% rapeseed meal)						
Slurry application timing: Summer	Slurry (maize) fate-Slurry (oilseed rape) fate	4				
Beef cattle diet: H. 3874 kgDM grazing	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.9				
Beef cattle diet: C. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM lucerne silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.9				
Beef cattle diet: G. 2411 kgDM grazing; 415 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.4				
Beef cattle diet: A. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.3				
Overpowered tractor not used: Yes	Mowing-Ploughing (barley)-Discing (maize)-Harrow (maize)-Ploughing (maize)-Ploughing (oilseed rape)-Subsoiling (35 cm) (oilseed rape)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Rolling (wheat)-Slurry (barley) application-Slurry (maize) application-Slurry (oilseed rape) application	1.1				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (grassland) manufacture-Inorganic fertiliser (maize) manufacture-Inorganic fertiliser	1.1			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	(oilseed rape) manufacture-Inorganic fertiliser (wheat) manufacture				yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Types of drill: Conventional drill	Drilling (wheat)	0.6				
Types of drill: Direct drill	Drilling (wheat)	0.6				
Beef cattle diet: E. 2411 kgDM grazing; 1263 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.7				
Maximum traction efficiency obtained (10-15% wheel slip): Yes	Mowing-Ploughing (barley)-Discing (maize)-Harrow (maize)-Ploughing (maize)-Ploughing (oilseed rape)-Subsoiling (35 cm) (oilseed rape)-Drilling (wheat)-Harrow (wheat)-Ploughing (wheat)-Rolling (wheat)-Slurry (barley) application-Slurry (maize) application-Slurry (oilseed rape) application	0.6			- Ensuring maximum traction efficiency will reduce fuel use.	
Types of disc: Disc (5.5m)	Discing (maize)	0.5				
Slurry incorporation technique: Deep injection (25-30cm)	Slurry (maize) fate-Slurry (oilseed rape) fate	0.3		Potential improvements to air quality Potential improvements to air quality		
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (maize)-Ploughing (oilseed rape)-Ploughing (wheat)	0.2			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Types of disc: Heavy discs	Discing (maize)	0.2				
Slurry incorporation technique: Soil incorporated (< 6 hours)	Slurry (maize) fate-Slurry (oilseed rape) fate	0.2		Potential improvements to air quality Potential improvements to air quality		
Straw chopping: No	Harvest barley-Harvest oilseed rape-Harvest wheat	0.1				
Ploughing depth: 20 cm	Ploughing (barley)-Ploughing (maize)-Ploughing (oilseed rape)-Ploughing (wheat)	0.1			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to grassland (t)	14	13.45 tCO2e per t	0.5	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on grass growth and yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to maize (t)	36	12.7 tCO2e per t	0.4	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to oilseed rape (t)	21	7.38 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on oilseed rape yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	7.5	7.39 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	50	7.38 tCO2e per t	0.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Number of beef cattle (head)	500	2.43 tCO2e per head	0.1	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Area of barley sprayed with pesticides (liquids) (ha)	60	0.01 tCO2e per ha	0	0		Unknown
Amount of insecticide used on barley (kg)	1.2	1.23 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of maize sprayed with pesticides (liquids) (ha)	300	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of fungicide used on barley (kg)	1.5	0.99 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of oilseed rape to which inorganic fertiliser is applied (ha)	120	0 tCO2e per ha	0	0		Unknown
Amount of herbicide used on barley (kg)	120	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Area of wheat to which inorganic fertiliser is applied (ha)	300	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of maize to which inorganic fertiliser is applied (ha)	300	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on maize yields. Review N use practices to ensure they are optimal and match crop requirements.
Area of grassland to which inorganic fertiliser is applied (ha)	60	0 tCO2e per ha	0	0		Unknown
Amount of herbicide used on maize (kg)	600	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Area of barley to which inorganic fertiliser is applied (ha)	60	0 tCO2e per ha	0	0		Unknown
Area of grassland (ha)	60	0.01 tCO2e per ha	0	0	Potential physical damage to soil	Unknown
Number of times per year that the grass is cut (Number)	4	0.96 tCO2e per Number	0	0		Unknown
Area of grassland cut (ha)	60	0.06 tCO2e per ha	0	0		Unknown
Area of barley harvested (ha)	60	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	330	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of oilseed rape harvested (ha)	120	0.05 tCO2e per ha	0	0		Reducing the area of oilseed rape may decrease total yield unless yields per hectare increase.
Tonnes of wheat harvested (tonne)	1800	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	300	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Tonnes of oilseed rape harvested (tonne)	420	0.01 tCO2e per tonne	0	0		Reducing the amount of oilseed rape harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of insecticide used on maize (kg)	6	1.22 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce maize yields. Review the pesticide use strategy to ensure it is optimal.
Tonnes of maize harvested (tonne)	15000	0 tCO2e per tonne	0	0		Reducing the amount of maize harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Amount of beef slurry (6% DM) applied to oilseed rape (tonne)	2400	0.02 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Area harrowed (wheat) (ha)	300	0.02 tCO2e per ha	0	0		Unknown
Area subsoiled (oilseed rape) (ha)	120	0.02 tCO2e per ha	0	0		Unknown
Total area of oilseed rape (ha)	120	0 tCO2e per ha	0	0		Unknown
Area ploughed (oilseed rape) (ha)	120	0.13 tCO2e per ha	0	0		Unknown
Area drilled (wheat) (ha)	300	0.08 tCO2e per ha	0	0		Unknown
Area ploughed (wheat) (ha)	300	0.13 tCO2e per ha	0	0		Unknown
Area ploughed (maize) (ha)	300	0.13 tCO2e per ha	0	0		Unknown
Total area of wheat (ha)	300	0 tCO2e per ha	0	0		Unknown
Amount of beef slurry (6% DM) applied to maize (tonne)	5400	0.02 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Amount of beef slurry (6% DM) applied to barley (tonne)	900	0.02 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Area rolled (wheat) (ha)	300	0.01 tCO2e per ha	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Total area of maize (ha)	300	0 tCO2e per ha	0	0		Unknown
Area harrowed (maize) (ha)	300	0.02 tCO2e per ha	0	0		Unknown
Amount of insecticide used on oilseed rape (kg)	3.5	0.23 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on wheat (kg)	300	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat sprayed with pesticides (liquids) (ha)	300	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of fungicide used on oilseed rape (kg)	3	0.27 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of herbicide used on oilseed rape (kg)	60	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce oilseed rape yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	6	0.63 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	6	0.63 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area discing (maize) (ha)	300	0.07 tCO2e per ha	0	0		Unknown
Area harrowed (barley) (ha)	60	0.02 tCO2e per ha	0	0		Unknown
Area rolled (barley) (ha)	60	0.01 tCO2e per ha	0	0		Unknown
Total area of barley (ha)	60	0 tCO2e per ha	0	0		Unknown
Area ploughed (barley) (ha)	60	0.13 tCO2e per ha	0	0		Unknown
Area of oilseed rape sprayed with pesticides (liquids) (ha)	120	0.01 tCO2e per ha	0	0		Unknown

A6.2. Martjanci, Slovenia (cattle, pigs and cereals)

Description:

Enterprises:	• Cattle rearing • Cereals • Pig fattening
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Beef cattle manure storage • Harrow (barley) • Harrow (wheat) • Harvest barley • Harvest wheat • Indoor finishers (medium) heating, lighting and ventilation • Indoor finishers (medium) slurry storage • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Inorganic fertiliser (grassland) application • Inorganic fertiliser (grassland) fate • Inorganic fertiliser (grassland) manufacture • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Load manure (barley) • Load manure (wheat) • Mowing • Pesticide application - liquids (wheat) • Pesticide manufacture (barley) • Pesticide manufacture (wheat) • Ploughing (barley) • Ploughing (wheat) • Prevention of compaction on cultivated land (barley) • Prevention of compaction on cultivated land (wheat) • Prevention of compaction on grassland • Slurry (grassland) application • Slurry (grassland) fate • Solid manure (barley) application • Solid manure (barley) fate • Solid manure (wheat) application • Solid manure (wheat) fate
Modifiers:	• Archaeological features: No archaeological features • Beef cattle diet: F. 1929 kgDM grazing; 482 kg DM clover; 115 kgDM grass hay average; 1148 kgDM grass silage; 1914 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Beef cattle manure store: Deep bedding - no mixing (stored for >1 month) • Beef cattle manure temperature: 12 C • Beef cattle production system: Lowland suckler cattle herd (autumn calving) • Correct siting and accurate temperature sensors: Yes • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Distance between beef manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Enclosed creep, heater lamp automatic control and dimmer switches: Yes • Energy/fuel source (Buildings): Gas/diesel oil • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Ensure insulation always dry: Yes • Fans interlinked to heaters (heaters on only when fans low): No • Feeding troughs moved frequently: Yes (or n.a.) • Grassland not entered with heavy machinery when wet: Yes • High power to weight ratio tractor used: Yes • Insulated enclosed creep: Yes • Location: Southern Europe

	• Lying area panels on flat decks: Yes • Manure application technique: Soil incorporated (24 hours) • Manure application timing: Autumn • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: Yes • Pesticide sprayer equipment: Tractor and sprayer • Pig housing - Low energy lighting: Yes • Pig housing ventilation - Fan and ventilation functioning optimally and openings checked frequently for obstructions: Yes • Pig housing ventilation - Flat deck with correct number of fans : Yes • Pig Indoor finishers (medium) unit size: Small (up to 1200 head) • Pig slurry store: Liquid/Slurry with natural crust cover • Pig slurry temperature: Unknown • Ploughing depth: 20 cm • Rainfall forecasting used: Yes • Rainfall: >700mm • Slurry application technique: Injection • Slurry application timing: Spring • Slurry incorporation technique: Soil incorporated (6-8 hours) • Soil aerator used on compacted areas (cultivated land): No • Soil aerator used on compacted areas (grassland): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 2: Mineral • Soil type 3: Deep fertile silty soils • Soil type 4: Heavy / medium • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of harrow: Spring tine harrows / weeding • Types of manure applied: Cattle FYM - old • Types of mower: Mower • Types of pesticide: Fungicide, Herbicide, Insecticide • Types of slurry applied: Pig slurry (4% DM) • Tyres inflated correctly: Yes • Under floor heating, heated pads: No • Vehicles serviced regularly: Yes

Item	**Value**
Number of beef cattle	290
Percentage of year beef cattle are housed	100 Percentage (0 to 100)
Area of grassland cut	15 ha
Number of times per year that the grass is cut	4
Area of grassland	15 ha
Area of barley harvested	30 ha
Tonnes of barley harvested	150 t
Area of wheat harvested	130 ha
Tonnes of wheat harvested	780 t
Number of pigs (Indoor finishers - medium)	400
Percentage of year pigs (indoor finishers - medium) unit is occupied	80 Percentage (0 to 100)
Area of barley to which inorganic fertiliser is applied	30 Hectare
Amount of nitrogen applied to barley	3.6 Tonnes of Nitrogen
Area of grassland to which inorganic fertiliser is applied	15 ha
Amount of nitrogen applied to grassland	2.7 Tonnes of Nitrogen
Area of wheat to which inorganic fertiliser is applied	130 ha
Amount of nitrogen applied to wheat	19.5 Tonnes of Nitrogen

Item	Value
Amount of insecticide used on barley	0.6 Kilograms of active substance
Amount of herbicide used on barley	30 Kilograms of active substance
Amount of fungicide used on barley	0.6 Kilograms of active substance
Area of wheat sprayed with pesticides (liquids)	130 ha
Amount of fungicide used on wheat	2.6 Kilograms of active substance
Amount of herbicide used on wheat	300 Kilograms of active substance
Amount of insecticide used on wheat	2.6 Kilograms of active substance
Area harrowed (barley)	30 ha
Area ploughed (barley)	30 ha
Total area of barley	30 ha
Area harrowed (wheat)	130 ha
Area ploughed (wheat)	130 ha
Total area of wheat	130 ha
Amount of pig slurry (4% DM) applied to grassland	300 t
Amount of cattle FYM (old) applied to barley	900 t
Area of barley to which solid manure is applied	30 ha
Amount of cattle FYM (old) applied to wheat	3250 t
Area of wheat to which solid manure is applied	130 ha
Total head of cattle reared	290
Tonnes of pig meat output	200 t

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	780 Tonnes	0.341 tCO2e per tonne	0.003 tCO2 per tonne
Barley	150 Tonnes	0.752 tCO2e per tonne	0.02 tCO2 per tonne
Head of cattle reared	290 Number	2.931 tCO2e per head	0 tCO2 per head
Pig meat	200 Tonnes	0.098 tCO2e per t	0 tCO2 per t

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Beef cattle	801.36				<1%-21%
Solid manure applications (wheat)	311.75	2.5 (for 113 years)			<1%-0%
Inorganic fertiliser (wheat)	122.4		Potential negative impact on groundwater quality		<1%-6%
Solid manure applications (barley)	86.33	3 (for 94 years)			<1%-0%
Inorganic fertiliser (grassland)	36.33		Potential negative impact on groundwater quality		<1%
Indoor finishers (medium)	23.31		Potential negative impact on air quality		<1%-2%

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Inorganic fertiliser (barley)	22.62		Potential negative impact on groundwater quality		<1%
Slurry applications (grassland)	11.47		Potential negative impact on air quality		<1%
Seedbed preparation/soil management (wheat)	8.58				<1%
Harvesting (wheat)	6.35				<1%
Pesticides (wheat)	4.33				0%
Seedbed preparation/soil management (barley)	1.98				<1%
Harvesting (barley)	1.43				<1%
Grassland management	0.78				0%
Pesticides (barley)	0.38				0%
Total	**1439.4**	**5.5**			**<1%-30%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Beef cattle manure store: Solid storage (unconfined piles or stacks)	Beef cattle manure storage	18.5				
Beef cattle manure store: Deep bedding - no mixing (stored for <1 month)	Beef cattle manure storage	13.9				
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate-Inorganic fertiliser (wheat) fate	6.2		Potential improvements to groundwater quality		
Beef cattle manure store: Dry lot (paved or unpaved open confinement area)	Beef cattle manure storage	4.5				
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle manure storage	2.7				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60%	Beef cattle enteric fermentation-Beef cattle manure storage	2.6				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
wheatfeed; 20% barley; 20% rapeseed meal)						
Beef cattle diet: C. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM lucerne silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle manure storage	2.1				
Pig slurry store: Anaerobic digestion	Indoor finishers (medium) slurry storage	1.4		Potential improvements to air quality	- Anaerobic digestion or biogas plants can be very expensive to construct (e.g. €200K). - Grants are available in some countries to cover capital costs. - Methane from biogas plants can be used a source of fuel on farms.	
Pig slurry store: Pit storage below animal confinements (stored for <1 month)	Indoor finishers (medium) slurry storage	1		Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Pig slurry store: Liquid Aerobic treatment - forced aeration	Indoor finishers (medium) slurry storage	1		Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					with size. Savings may be made if better management means better use of nutrients.	
Pig slurry store: Liquid Aerobic treatment - natural aeration	Indoor finishers (medium) slurry storage	0.8		Potential decrease in air quality	- A new slurry store may cost typically between €10k and €30K depending upon size and type. Operating costs increase with size. Savings may be made if better management means better use of nutrients.	
Beef cattle diet: G. 2411 kgDM grazing; 415 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle manure storage	0.5				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture-Inorganic fertiliser (grassland) manufacture-Inorganic fertiliser (wheat) manufacture	0.4			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Pig slurry temperature: <10 C	Indoor finishers (medium) slurry storage	0.4		Potential improvements to air quality	- Energy/fuel may be required to cool	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					slurry (this may be lower in northern climates).	
Manure application timing: Spring	Solid manure (barley) fate-Solid manure (wheat) fate	0.3	5.5			
Ploughing depth: 15 cm	Ploughing (barley)-Ploughing (wheat)	0.2			- The deeper the ploughing depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	
Beef cattle diet: A. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle manure storage	0.2				
Manure application timing: Winter	Solid manure (barley) fate-Solid manure (wheat) fate	0.2	5.5			
Pig slurry temperature: 12 C	Indoor finishers (medium) slurry storage	0.2		Potential improvements to air quality	- Energy/fuel may be required to cool slurry (this may be lower in northern climates).	
Fans interlinked to heaters (heaters on only when fans low): Yes	Indoor finishers (medium) heating, lighting and ventilation	0.1				
Under floor heating, heated pads: Yes	Indoor finishers (medium) heating, lighting and	0.1				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	ventilation					
Slurry application technique: Trailing hose	Slurry (grassland) application	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to grassland (t)	2.7	13.45 tCO2e per t	0.9	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on grass growth and yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to barley (t)	3.6	6.28 tCO2e per t	0.4	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Amount of nitrogen applied to wheat (t)	19.5	6.28 tCO2e per t	0.4	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Percentage of year beef cattle are housed (%)	100	4.38 tCO2e per %	0.3	0		Unknown
Number of beef cattle (head)	290	2.76 tCO2e per head	0.2	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Amount of insecticide used on wheat (kg)	2.6	1.42 tCO2e per kg	0.1	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of fungicide used on wheat (kg)	2.6	1.42 tCO2e per kg	0.1	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat to which solid manure is applied (ha)	130	0.92 tCO2e per ha	0.1	0.02		Unknown
Area of barley to which solid manure is applied (ha)	30	1.11 tCO2e per ha	0.1	0.1		Unknown
Number of pigs (Indoor finishers - medium) (head)	400	0.06 tCO2e per head	0	0	Potential negative impact on air quality	Reducing the number of pigs will directly reduce output unless output per pig can be increased.
Total area of	30	0 tCO2e per	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
barley (ha)		ha				
Tonnes of wheat harvested (tonne)	780	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Percentage of year pigs (indoor finishers - medium) unit is occupied (%)	80	0.29 tCO2e per %	0	0	▲ Potential negative impact on air quality	Reductions in occupancy may directly reduce farm output unless output during occupancy can be increased.
Tonnes of barley harvested (tonne)	150	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of wheat harvested (ha)	130	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of barley harvested (ha)	30	0.05 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Amount of cattle FYM (old) applied to barley (tonne)	900	0.1 tCO2e per tonne	0	0		Unknown
Area of grassland cut (ha)	15	0.05 tCO2e per ha	0	0		Unknown
Number of times per year that the grass is cut (Number)	4	0.2 tCO2e per Number	0	0		Unknown
Area of grassland (ha)	15	0 tCO2e per ha	0	0		Unknown
Area of barley to which inorganic fertiliser is applied (ha)	30	0 tCO2e per ha	0	0		Unknown
Area of grassland to which inorganic fertiliser is applied (ha)	15	0 tCO2e per ha	0	0		Unknown
Area ploughed (barley) (ha)	30	0.05 tCO2e per ha	0	0		Unknown
Area of wheat sprayed with pesticides (liquids) (ha)	130	0 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of herbicide used on wheat (kg)	300	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area harrowed (wheat) (ha)	130	0.02 tCO2e per ha	0	0		Unknown
Area harrowed (barley) (ha)	30	0.02 tCO2e per ha	0	0		Unknown
Area ploughed (wheat) (ha)	130	0.05 tCO2e per ha	0	0		Unknown
Amount of fungicide used on barley (kg)	0.6	0.63 tCO2e per kg	0	0		Reducing the amount of fungicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Amount of pig slurry (4% DM) applied to grassland (tonne)	300	0.04 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Amount of herbicide used on barley (kg)	30	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat to which inorganic fertiliser is applied (ha)	130	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Total area of wheat (ha)	130	0 tCO2e per ha	0	0		Unknown
Amount of cattle FYM (old) applied to wheat (tonne)	3250	0.1 tCO2e per tonne	0	0		Unknown
Amount of insecticide used on barley (kg)	0.6	0.63 tCO2e per kg	0	0		Reducing the amount of insecticide used could reduce barley yields. Review the pesticide use strategy to ensure it is optimal.

A6.3. Bloke, Slovenia (cattle and cereals)

Description:

Enterprises:	• Cattle fattening • Cattle rearing • Cereals
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Beef cattle manure storage • Create hedgerows on grassland • Harrow (wheat) • Harvest wheat • Inorganic fertiliser (wheat) application • Inorganic fertiliser (wheat) fate • Inorganic fertiliser (wheat) manufacture • Mowing • Pesticide application - liquids (wheat) • Pesticide manufacture (wheat) • Ploughing (wheat) • Prevention of compaction on cultivated land (wheat) • Prevention of compaction on grassland • Slurry (grassland) application • Slurry (grassland) fate • Slurry (wheat) application • Slurry (wheat) fate
Modifiers:	• Archaeological features: No archaeological features • Beef cattle diet: A. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Beef cattle manure store: Solid storage (unconfined piles or stacks) • Beef cattle manure temperature: 15 C or Unknown • Beef cattle production system: Upland suckler cattle herd (autumn calving) • Biodiversity designations: Special Protection Area (SPA) or equivalent • Correct tyres used (reduce rolling resistance): Yes • Cultivated land field not entered with heavy machinery when wet: Yes • Distance between beef manure stores and surface water or drains: Greater than 10 metres • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Production of pesticides): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • Feeding troughs moved frequently: Yes (or n.a.) • Grassland not entered with heavy machinery when wet: Yes • High power to weight ratio tractor used: No • Landscape designations: Area of Outstanding Natural Beauty (AONB) (or equivalent) • Location: Southern Europe • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 20 cm • Rainfall forecasting used: Yes • Rainfall: >700mm • Slurry application technique: Trailing hose • Slurry application timing: Spring • Slurry incorporation technique: Surface application • Soil aerator used on compacted areas (cultivated land): No • Soil aerator used on compacted areas (grassland): No • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 2: Mineral • Soil type 3: Shallow soils over rock • Soil type 4: Heavy / medium • Straw chopping: Yes • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of harrow: Spring tine harrows / weeding

	• Types of mower: Mower • Types of pesticide: Fungicide, Herbicide, Insecticide • Types of slurry applied: Beef slurry (6% DM) • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Number of beef cattle	52
Percentage of year beef cattle are housed	70 Percentage (0 to 100)
Area of grassland converted to hedgerows	1 ha
Area of grassland cut	25 ha
Number of times per year that the grass is cut	3
Area of grassland	39 ha
Area of wheat harvested	7 ha
Tonnes of wheat harvested	38 t
Area of wheat to which inorganic fertiliser is applied	7 ha
Amount of nitrogen applied to wheat	0.8 Tonnes of Nitrogen
Area of wheat sprayed with pesticides (liquids)	7 ha
Amount of fungicide used on wheat	0.14 Kilograms of active substance
Amount of herbicide used on wheat	7 Kilograms of active substance
Amount of insecticide used on wheat	0.14 Kilograms of active substance
Area harrowed (wheat)	7 ha
Area ploughed (wheat)	7 ha
Total area of wheat	7 ha
Amount of beef slurry (6% DM) applied to grassland	500 t
Amount of beef slurry (6% DM) applied to wheat	140 t
Tonnes of beef output	18 Tonnes Live Weight
Total head of cattle reared	52

Results summary:

Output	Quantity	Emissions	Sequestration
Wheat	38 Tonnes	0.224 tCO2e per tonne	0 tCO2 per tonne
Head of cattle reared	52 Number	1.12 tCO2e per head	0 tCO2 per head
Beef	18 Tonnes Live Weight	3.234 tCO2e per t LW	0.397 tCO2 per t LW

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Beef cattle	96.09				<1%-6%
Slurry applications (grassland)	19.2		Potential negative impact on air quality		<1%-11%
Inorganic fertiliser (wheat)	5.34		Potential negative impact on groundwater quality		<1%-3%
Slurry applications (wheat)	3.36		Potential negative		<1%-2%

			impact on air quality		
Grassland management	1.15				<1%
Seedbed preparation/soil management (wheat)	0.54				<1%
Harvesting (wheat)	0.34				<1%
Pesticides (wheat)	0.13				0%
Environmental features	0	7.15 (for 11 to 140 years)	Potential positive impact on landscape quality Potential positive impact on bird populations		0%
Total	**126.14**	**7.15**			**<1%-21%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)-Beef cattle manure storage	5.3				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)-Beef cattle manure storage	5				
Nitrification inhibitors used: Yes	Inorganic fertiliser (wheat) fate	2.6		Potential improvements to groundwater quality		
Slurry incorporation technique: Deep injection (25-30cm)	Slurry (grassland) fate-Slurry (wheat) fate	1.6		Potential improvements to air quality Potential improvements to air quality		
Beef cattle diet: C. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM lucerne silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)-Beef cattle manure storage	1.3				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Slurry incorporation technique: Soil incorporated (< 6 hours)	Slurry (grassland) fate-Slurry (wheat) fate	1.3		Potential improvements to air quality Potential improvements to air quality		
Overpowered tractor not used: Yes	Mowing-Harrow (wheat)-Ploughing (wheat)-Slurry (grassland) application-Slurry (wheat) application	1				
Slurry incorporation technique: Soil incorporated (6-8 hours)	Slurry (grassland) fate-Slurry (wheat) fate	0.7		Potential improvements to air quality Potential improvements to air quality		
Beef cattle diet: G. 2411 kgDM grazing; 415 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)-Beef cattle manure storage	0.4				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (wheat) manufacture	0.2			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
High power to weight ratio tractor used: Yes	Mowing-Harrow (wheat)-Ploughing (wheat)-Slurry (grassland) application-Slurry (wheat) application	0.2				
Ploughing depth: 15 cm	Ploughing (wheat)	0.1			- The deeper the ploughing	

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
					depth the higher the financial cost and the longer the time cultivations will take. For example if ploughing at 25 cm depth rather than 15cm depth, the cost of establishing cereals may be more than 50% higher and cultivations take 40% longer.	

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to wheat (t)	0.8	6.67 tCO2e per t	5.3	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal.
Number of beef cattle (head)	52	1.85 tCO2e per head	1.5	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Amount of fungicide used on wheat (kg)	0.14	0.64 tCO2e per kg	0.5	0		Reducing the amount of fungicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Amount of insecticide used on wheat (kg)	0.14	0.64 tCO2e per kg	0.5	0		Reducing the amount of insecticide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Number of times per year that the grass is cut (Number)	3	0.38 tCO2e per Number	0.3	0		Unknown
Total area of wheat (ha)	7	0 tCO2e per ha	0	0		Unknown
Area of grassland (ha)	39	0 tCO2e per ha	0	0		Unknown
Area of grassland cut (ha)	25	0.05 tCO2e per ha	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Tonnes of wheat harvested (tonne)	38	0.01 tCO2e per tonne	0	0		Reducing the amount of wheat harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Area of grassland converted to hedgerows (ha)	1	0 tCO2e per ha	0	7.15	Potential positive impact on landscape quality Potential positive impact on bird populations	Reducing the area of grassland may have a direct economic impact on output, unless the land that is taken out of cultivation is of low productive capability.
Area of wheat harvested (ha)	7	0.05 tCO2e per ha	0	0		Reducing the area of wheat may decrease total yield unless yields per hectare increase.
Area of wheat to which inorganic fertiliser is applied (ha)	7	0 tCO2e per ha	0	0		Changes in the area to which inorganic N is applied may have a significant impact on wheat yields. Review N use practices to ensure they are optimal and match crop requirements.
Area ploughed (wheat) (ha)	7	0.06 tCO2e per ha	0	0		Unknown
Amount of beef slurry (6% DM) applied to grassland (tonne)	500	0.04 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Area harrowed (wheat) (ha)	7	0.02 tCO2e per ha	0	0		Unknown
Amount of herbicide used on wheat (kg)	7	0.01 tCO2e per kg	0	0		Reducing the amount of herbicide used could reduce wheat yields. Review the pesticide use strategy to ensure it is optimal.
Area of wheat sprayed with pesticides (liquids) (ha)	7	0.01 tCO2e per ha	0	0		Reducing the area wheat that is treated with pesticides could reduce wheat yields. Review pesticide use strategy to ensure it is optimal. Consider precision agriculture techniques to ensure that pesticides are only applied to areas where they are needed.
Amount of beef slurry (6% DM) applied to wheat (tonne)	140	0.02 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Percentage of year beef cattle are housed (%)	70	-0.23 tCO2e per %	-0.2	0		Unknown

A7. United Kingdom

A7.1. Drumdow, Stranraer, United Kingdom (cattle, sheep and cereals)

Description:

Enterprises:	• Cattle rearing • Cereals • Sheep
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Harrow (barley) • Harvest barley • Inorganic fertiliser (barley) application • Inorganic fertiliser (barley) fate • Inorganic fertiliser (barley) manufacture • Load manure (grassland) • Mowing • Pesticide application - liquids (barley) • Pesticide manufacture (barley) • Ploughing (barley) • Sheep enteric fermentation • Sheep excreta (deposition on pasture) • Solid manure (grassland) application • Solid manure (grassland) fate
Modifiers:	• Archaeological features: Some archaeological features (moderate value, some legal protection) • Beef cattle diet: H. 3874 kgDM grazing • Beef cattle production system: Upland suckler cattle herd (spring calving) • Correct tyres used (reduce rolling resistance): Yes • Do not cultivate in poor conditions: Yes • Driver aids used: Yes • Energy/fuel source (Production of inorganic N fertiliser): Grid electricity • Energy/fuel source (Production of pesticides): Grid electricity • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: No • Location: Northern Europe • Manure application technique: Soil incorporated (24 hours) • Manure application timing: Autumn • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Nitrate Vulnerable Zone (NVZ): No • Nitrification inhibitors used: No • Overpowered tractor not used: No • Pesticide sprayer equipment: Tractor and sprayer • Ploughing depth: 15 cm • Rainfall forecasting used: Yes • Rainfall: >700mm • Sheep diet: E. 436.4 kgDM grazing; 35kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Sheep production system: Lowland spring lamb (early) flock • Soil Nitrogen Supply (SNS) known: Yes • Soil type 1: Loam • Soil type 2: Mineral • Soil type 3: Shallow soils over rock • Soil type 4: Heavy / medium • Straw chopping: No • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of harrow: Spring tine harrows / weeding • Types of manure applied: Cattle FYM - old • Types of mower: Mower-conditioner • Types of pesticide: Herbicide • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Number of beef cattle	186
Percentage of year beef cattle are housed	0 Percentage (0 to 100)
Area of grassland cut	36 ha
Number of times per year that the grass is cut	2
Area of barley harvested	6.5 ha
Tonnes of barley harvested	35 t
Area of barley to which inorganic fertiliser is applied	6.5 Hectare
Amount of nitrogen applied to barley	2 Tonnes of Nitrogen
Area of barley sprayed with pesticides (liquids)	6.5 ha
Amount of herbicide used on barley	0 Kilograms of active substance
Area harrowed (barley)	6.5 ha
Area ploughed (barley)	6.5 ha
Number of sheep	240
Percentage of year sheep are housed	0.3 Percentage (0 to 100)
Amount of cattle FYM (old) applied to grassland	500 t
Area of grassland to which solid manure is applied	10 ha
Total head of cattle reared	160

Results summary:

Output	Quantity	Emissions	Sequestration
Barley	35 Tonnes	0.413 tCO2e per tonne	0 tCO2 per tonne
Head of cattle reared	160 Number	2.71 tCO2e per head	0.031 tCO2 per head

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Beef cattle	379.15				<1%-8%
Solid manure applications (grassland)	52.96	5 (for 56 years)			<1%-1%
Sheep	51.68				<1%
Inorganic fertiliser (barley)	13.77		Potential negative impact on groundwater quality		<1%-2%
Grassland management	1.53				<1%
Seedbed preparation/soil management (barley)	0.35		Potential negative impact on archaeological sites and features		0%
Harvesting (barley)	0.29				0%
Pesticides (barley)	0.04				0%
Total	**499.77**	**5**			**<1%-11%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	7.7				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	7.1				
Nitrification inhibitors used: Yes	Inorganic fertiliser (barley) fate	1.6		Potential improvements to groundwater quality		
Overpowered tractor not used: Yes	Mowing-Solid manure (grassland) application	0.9				
Sheep diet: F. 471.4 kgDM grazing	Sheep excreta (deposition on pasture)	0.3				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (barley) manufacture	0.2			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Types of mower: Mower	Mowing	0.1				
Manure application timing: Spring	Solid manure (grassland) fate	0.1	5			
Manure application timing: Winter	Solid manure (grassland) fate	0.1	5			

Modification	Components	% reduction of total emissions	tCO_2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
High power to weight ratio tractor used: Yes	Mowing-Solid manure (grassland) application	0.1				

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Amount of nitrogen applied to barley (t)	2	6.89 tCO2e per t	1.4	0	Potential negative impact on groundwater quality	Changes in N applied may have a significant impact on barley yields. Review N use practices to ensure they are optimal.
Area of grassland to which solid manure is applied (ha)	10	1.85 tCO2e per ha	0.4	0.5		Unknown
Number of beef cattle (head)	186	2.04 tCO2e per head	0.4	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Number of times per year that the grass is cut (Number)	2	0.76 tCO2e per Number	0.2	0		Unknown
Area of grassland cut (ha)	36	0.04 tCO2e per ha	0	0		Unknown
Number of sheep (head)	240	0.22 tCO2e per head	0	0		Unknown
Area of barley harvested (ha)	6.5	0.04 tCO2e per ha	0	0		Reducing the area of barley may decrease total yield unless yields per hectare increase.
Tonnes of barley harvested (tonne)	35	0.01 tCO2e per tonne	0	0		Reducing the amount of barley harvested will have direct economic impact, unless a higher quality and price can be achieved per tonne harvested.
Percentage of year sheep are housed (%)	0.3	-0.16 tCO2e per %	0	0		Unknown
Amount of cattle FYM (old) applied to grassland (tonne)	500	0.11 tCO2e per tonne	0	0.01		Unknown
Area ploughed (barley) (ha)	6.5	0.04 tCO2e per ha	0	0	Potential negative impact on archaeological sites and features	Unknown
Area harrowed	6.5	0.02 tCO2e	0	0		Unknown

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
(barley) (ha)		per ha				
Area of barley sprayed with pesticides (liquids) (ha)	6.5	0.01 tCO2e per ha	0	0		Unknown
Area of barley to which inorganic fertiliser is applied (ha)	6.5	0 tCO2e per ha	0	0		Unknown

A7.2. Viewfield, Castle Douglas, United Kingdom (cattle and sheep)

Description:

Enterprises:	• Cattle rearing • Sheep
Components:	• Beef cattle enteric fermentation • Beef cattle excreta (deposition on pasture) • Inorganic fertiliser (grassland) application • Inorganic fertiliser (grassland) manufacture • Mowing • Rake • Sheep enteric fermentation • Sheep excreta (deposition on pasture) • Slurry (grassland) application • Slurry (grassland) fate
Modifiers:	• Beef cattle diet: E. 2411 kgDM grazing; 1263 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Beef cattle production system: Upland suckler cattle herd (spring calving) • Correct tyres used (reduce rolling resistance): Yes • Driver aids used: No • Energy/fuel source (Production of inorganic N fertiliser): Gas/diesel oil • Energy/fuel source (Vehicles): Gas/diesel oil • High power to weight ratio tractor used: Yes • Location: Northern Europe • Maximum traction efficiency obtained (10-15% wheel slip): Yes • Overpowered tractor not used: No • Rainfall: >700mm • Sheep diet: E. 436.4 kgDM grazing; 35kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal) • Sheep production system: Upland flock • Slurry application technique: Trailing hose • Slurry application timing: Spring • Slurry incorporation technique: Surface application • Soil type 4: Heavy / medium • Type of inorganic fertiliser: Ammonium nitrate (34.5% N) • Types of mower: Mower-conditioner • Types of rake: Rake • Types of slurry applied: Beef slurry (6% DM) • Tyres inflated correctly: Yes • Vehicles serviced regularly: Yes

Item	Value
Number of beef cattle	400
Percentage of year beef cattle are housed	50 Percentage (0 to 100)
Area of grassland cut	89 ha

Item	Value
Number of times per year that the grass is cut	1
Area of grassland to which inorganic fertiliser is applied	670 ha
Amount of nitrogen applied to grassland	35 Tonnes of Nitrogen
Number of sheep	2400
Percentage of year sheep are housed	0 Percentage (0 to 100)
Amount of beef slurry (6% DM) applied to grassland	1200 t
Total head of cattle reared	230

Results summary:

Output	Quantity	Emissions	Sequestration
Head of cattle reared	230 Number	3.009 tCO2e per head	0 tCO2 per head

Component	tCO2e emissions	tCO2 sequestration	Other impacts	Data Quality	Mitigation potential (% of total emissions)
Beef cattle	645.76				<1%-6%
Sheep	546.84				<1%-1%
Slurry applications (grassland)	28.92		Potential negative impact on air quality		<1%-2%
Inorganic fertiliser (grassland)	14.15				<1%
Grassland management	3.27				<1%
Total	**1238.93**				**<1%-9%**

Suggested mitigation options (practice changes):

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
Beef cattle diet: B. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM maize silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	5.8				
Beef cattle diet: D. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM wheat whole crop fermented; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	5.5				
Beef cattle diet: H. 3874 kgDM grazing	Beef cattle enteric fermentation-Beef cattle excreta (deposition on	1.5				

Modification	**Components**	**% reduction of total emissions**	**tCO2 sequestration (range)**	**Other impacts (net change)**	**Economic information**	**Data quality**
	pasture)					
Beef cattle diet: C. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM lucerne silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	1.5				
Beef cattle diet: G. 2411 kgDM grazing; 415 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.8				
Sheep diet: F. 471.4 kgDM grazing	Sheep excreta (deposition on pasture)	0.6				
Type of inorganic fertiliser: Ammonium sulphate (21% N; 60% SO3)	Inorganic fertiliser (grassland) manufacture	0.7			- More efficient use of fertilisers will reduce emissions and save money. Fertiliser planning and recording will optimise crop yields and minimise environmental losses. Soil sampling typically costs €24-30 per sample. Soil management plan may cost around €1000.	
Sheep diet: B. 400 kgDM grazing; 41.4 kgDM grass hay average; 30 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Sheep excreta (deposition on pasture)	0.6				
Beef cattle diet: A. 2411 kgDM grazing; 115 kgDM grass hay average; 1148 kgDM grass silage; 315 kgDM concentrates (60% wheatfeed; 20% barley; 20% rapeseed meal)	Beef cattle enteric fermentation-Beef cattle excreta (deposition on pasture)	0.5				
Overpowered tractor not used: Yes	Mowing-Rake-Inorganic fertiliser (grassland) application-Slurry (grassland)	0.2				

Modification	Components	% reduction of total emissions	tCO2 sequestration (range)	Other impacts (net change)	Economic information	Data quality
	application					
Slurry incorporation technique: Soil incorporated (< 6 hours)	Slurry (grassland) fate	0.2		Potential improvements to air quality		
Slurry incorporation technique: Deep injection (25-30cm)	Slurry (grassland) fate	0.2		Potential improvements to air quality		
Slurry incorporation technique: Soil incorporated (6-8 hours)	Slurry (grassland) fate	0.1		Potential improvements to air quality		

Suggested mitigation options (quantities):

Item	Quantity	Potential reduction in emissions per unit	% of Total emissions	Potential sequestration per unit	Potential other impacts	Potential Economic impact
Number of times per year that the grass is cut (Number)	1	3.26 tCO2e per Number	0.3	0		Unknown
Number of beef cattle (head)	400	1.61 tCO2e per head	0.1	0		Reducing the number of beef cattle will directly reduce output unless output per head can be increased.
Amount of nitrogen applied to grassland (t)	35	0.4 tCO2e per t	0	0		Changes in N applied may have a significant impact on grass growth and yields. Review N use practices to ensure they are optimal.
Area of grassland to which inorganic fertiliser is applied (ha)	670	0 tCO2e per ha	0	0		Unknown
Area of grassland cut (ha)	89	0.04 tCO2e per ha	0	0		Unknown
Number of sheep (head)	2400	0.23 tCO2e per head	0	0		Unknown
Amount of beef slurry (6% DM) applied to grassland (tonne)	1200	0.02 tCO2e per tonne	0	0	Potential negative impact on air quality	Unknown
Percentage of year beef cattle are housed (%)	50	-4.6 tCO2e per %	-0.4	0		Unknown